U.S. ARMY
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COMMAND

AD No. ______________________

TECOM Project No. 7-CO-M95-AVD-004

# FINAL REPORT

# METHODOLOGY INVESTIGATION

# GLOBAL POSITIONING SYSTEM (GPS) VEHICLE TRACKING SYSTEM

# FOR FLIGHT TESTING OF FIXED- AND ROTARY-WING AIRCRAFT


MR. LARRY MARTIN, TEST DIRECTOR/ENGINEER

UNITED STATES ARMY AVIATION TECHNICAL TEST CENTER
FORT RUCKER, ALABAMA 36362-5276


JUNE 1996

Period Covered:
June 1995 - April 1996

Prepared for:
Commander
U.S. Army Test and Evaluation
  Command
ATTN: AMSTE-CT-T
Aberdeen Proving Ground, MD
  21005-5055

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U.S. Army Test and Evaluation Command
Aberdeen Proving Ground, MD 21005-5055

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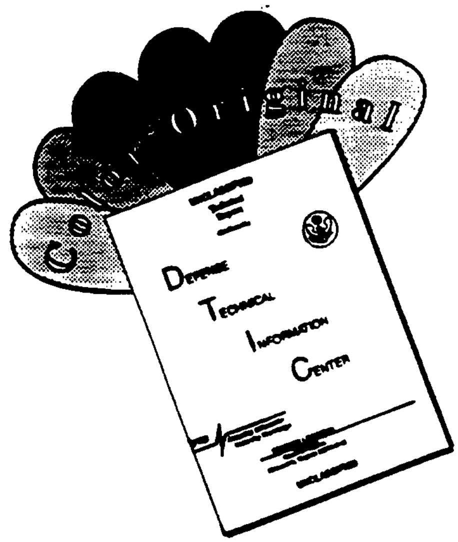


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ABERDEEN PROVING GROUND, MARYLAND 21005-5055

REPLY TO
ATTENTION OF

AMSTE-TM-T (70-10p)

26 Aug 96

MEMORANDUM FOR Commander, U.S. Army Aviation Technical Test Center, ATTN: STEAT-TS-D, Fort Rucker, AL 36362-5276

SUBJECT: Final Report, Methodology Investigation, Global Positioning System (GPS) Vehicle Tracking System for Flight Testing of Fixed- and Rotary-Wing Aircraft, TECOM Project No.7-CO-M95-AVD-004

1. Subject report is approved.

2. The TECOM point of contact is Mrs. Cyndie McMullen, AMSTE-TM-T, amstectt@apg-9.apg.army.mil, DSN 298-1469.

FOR THE COMMANDER:

for J. DAVID BROWN, Ph.D.
Chief, Simulation & Technology Division
Directorate for Technical Mission

# REPORT DOCUMENTATION PAGE

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| **12a. DISTRIBUTION/AVAILABILITY STATEMENT** Approved for public release; distribution is unlimited. | **12b. DISTRIBUTION CODE** |


**13. ABSTRACT (Maximum 200 words)** The U.S. Army Aviation Technical Test Center (ATTC) conducted the methodology investigation of the global positioning system (GPS) vehicle tracking system at White Sands Missile Range from June 1995-April 1996. The objectives were to quantify the accuracy of the GPS tracking system throughout the dynamics of normal helicopter flight and ensure that the rotor effect on the GPS signal reception is considered. It was concluded that the system as tested is capable of tracking helicopters through their flight envelope to an accuracy of less than 2 feet spherical error probable in real time, and the rotor system appeared to have little effect on the GPS signals.


| | |
|---|---|
| **14. SUBJECT TERMS** Methodology Investigation<br>Global Positioning System (GPS)<br>Time Space Positioning Information (TSPI)<br>Truth Data Acquisition Recording and Display System (TDARDS) | **15. NUMBER OF PAGES** 72 |
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TABLE OF CONTENTS

# FOREWORD

The U.S. Army Aviation Technical Test Center (ATTC) was responsible for planning, execution, and reporting of this methodology investigation.

All data for this report are filed at ATTC under TECOM Project No. 7-CO-M95-AVD-004.

ATTC gratefully acknowledges the contributions of the following personnel to this study:

Mr. Antonio Palomino, White Sands Missile Range
Mr. Mark Moeglein, Stanford Research Institute

# SECTION 1. SUMMARY

## 1.1 BACKGROUND

The U.S. Army Aviation Technical Test Center (ATTC), jointly with White Sands Missile Range (WSMR), developed a global positioning system (GPS) vehicle tracking system. ATTC uses the tracking system in flight testing to provide time space positioning information (TSPI) of fixed- and rotary-wing aircraft. The GPS tracking system, named the Truth Data Acquisition Recording and Display System (TDARDS), was designed to be a real-time tracking system capable of 1-meter root mean square (RMS) spherical error probable (SEP). TDARDS consists of a vehicle system or systems (up to 10 units), a ground system, and a data link. The TDARDS uses differential GPS technology with both carrier phase and code measurements to provide the very accurate position solution.

## 1.2 PROBLEM

Determine the baseline accuracy of the TDARDS so that ATTC can use the TDARDS in flight testing as a TSPI truth source.

## 1.3 OBJECTIVES

1.3.1 Quantify the accuracy of the TDARDS GPS tracking system throughout the dynamics of normal helicopter flight.

1.3.2 Ensure that the rotor effect on the GPS signal reception is considered.

## 1.4 PROCEDURES

1.4.1 ATTC conducted the accuracy measurement test at WSMR from June 1995 through April 1996. A UH-60L BLACKHAWK helicopter was used as the airborne platform, and the airborne GPS was mounted in the rear of the cargo area of the aircraft. The test was confined to a small area on the WSMR and optical tracking systems at WSMR were used as the truth data. All data produced in the report are with respect to the WSMR truth data.

1.4.2 Mounting of the GPS vehicle unit required mounting the GPS receiver antenna, GPS receiver, and data link antenna. Since the GPS antenna would be the tracking target used by WSMR optics, care was taken to ensure maximum visibility around the helicopter fuselage. The GPS antenna was mounted where the main fuselage and the tailboom meet, approximately 216 inches aft of the main rotor hub on the center line of the aircraft. The mount was a white rectangle 8 inches wide by 8 inches tall that affixed to the top of the tail rotor drive shaft cover. Six white stripes

were painted on each side of the airframe in an arrow shape pointing to the GPS antenna mount (figure (fig.) 1). The GPS receiver was mounted on the aircraft floor in the rear center of the cargo area. The data link antenna was mounted on the bottom of the aircraft on a cover made to fit over the cargo hook hole.

1.4.3 The GPS ground station consisted of two computers that were interconnected, a GPS reference receiver card, a GPS antenna, a data link transmitter, and a data link antenna. One of the computers was used to collect GPS data to correct the vehicle unit GPS, and the other computer was used to control the data link to the vehicle unit GPS.

1.4.3.1 To properly set up the GPS reference receiver computer, the GPS antenna had to be located over a first order surveyed point less than 30 meters away from the GPS reference receiver. The point at WSMR was on the roof of building 300. The location of the point was surveyed just prior to the testing.

1.4.3.2 The data link computer was located in building 300 directly adjacent to the reference receiver computer. The antenna for the data link computer was also located on the roof of building 300.

1.4.4 The optical trackers (cinetheodolites) at WSMR were located on the "Small Missile Range" in a rectangular pattern (fig. 2). There were two parallel rows of 3 trackers each; the rows were separated by approximately 7,000 feet, and the individual trackers in each row were 4,000 feet apart. A 2,500- by 6,000-foot box was centered and overlaid on the area of the trackers in which the aircraft maneuvers were completed.

1.4.5 The test was flown in accordance with (IAW) the test plan (appendix (app) A). Start times and stop times (app B) were determined when the helicopter entered and exited the maneuver box.

1.4.6 The test did not begin until the reference receiver indicated a GPS constellation of at least four satellites.

1.4.7 The GPS data to be collected were the raw measurements data (pseudorange, range rate, integrated carrier cycles, and integrated carrier phase) on board the vehicle and ground station for postmission processing (referred to as method 3) and the navigation solution (latitude, longitude, altitude) generated in the vehicle unit using the differential corrections generated by the ground station (referred to as method 1).


FIGURE 1. WHITE STRIPES POINTING TO WHITE GPS ANTENNA MOUNT

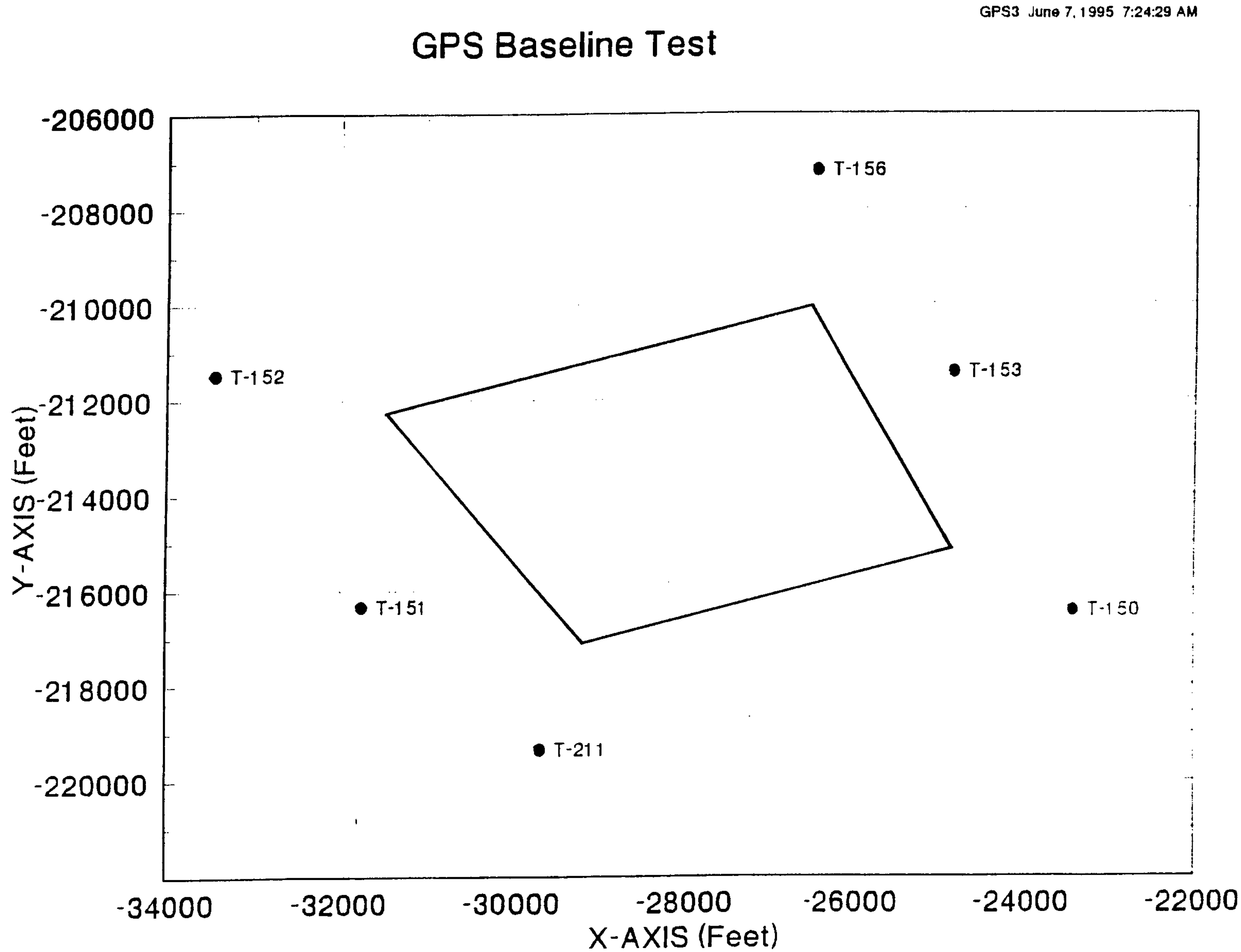


FIGURE 2. PATTERN OF OPTICAL TRACKERS AND MANEUVERING BOX

1.4.7.1 The postmission-processed GPS data used a process referred to as carrier averaging to produce the navigation solution from the raw measurements taken at the vehicle unit and ground station. The carrier averaging process was applied to the GPS receiver channel by channel (or satellite by satellite). Pseudorange and integrated carrier phase corrections were calculated by using the reference receiver data and the first order survey data and were individually applied to the airborne GPS receiver's code and carrier measurements. Once these corrections were applied, the difference between pseudorange and integrated carrier phase measurements was observed. The weighted average of this difference over the entire interval for which the satellite vehicle was in track determined the best estimate for the constant of carrier phase integration. On a second pass through the data, the stored constant of integration was added to the individual integrated carrier phase samples to form the best estimate of pseudorange. This best estimate of pseudorange data was then used in determining position (or a navigation solution) using a weighted least squares filter. Finally, this position solution was smoothed with differentially corrected velocity data, which were also derived from integrated carrier phase data.

1.4.7.2 The real-time navigation solution was calculated by using the pseudorange and integrated carrier phase differential corrections received from the ground station at the airborne GPS and individually applied to the GPS receiver's pseudorange and integrated carrier measurements. Once these corrections were applied, the difference between pseudorange and integrated carrier phase measurements was observed. The weighted average of this difference over the time the satellite vehicle had been in track (past data only) was used as an estimate for the constant of carrier phase integration. This constant was added to the most recent integrated carrier phase sample to form the best estimate of pseudorange. This best estimate of pseudorange data was then used in determining position (or the navigation solution) using a weighted least squares filter. (Note that the real-time (method 1) software does not currently perform the velocity smoothing found in the postmission (method 3) software.)

## 1.5 RESULTS

1.5.1 The GPS antenna installation on the UH-60L tailboom proved to be very effective for the WSMR test. The antenna provided a highly visible target from all aspect angles of the helicopter. The white-painted antenna mount also had a high contrast that was easily identifiable through the optical tracker video. The added stripes painted on the tailboom of the helicopter pointing to the antenna were visually helpful. The GPS antenna was mounted on the tailboom under the rotor, approximately two-thirds of the way down the rotor. This ensured that the GPS data were exposed to the interference problems associated with the rotor.

1.5.2 The reference receiver ground station could not be set up to operate in the method 1 mode of position solution (differential corrections transmitted to the aircraft and the position solution calculated on the aircraft and transmitted to the ground station). This turned out to be caused by a setup problem with the third RS-232 port on the ground station. This port is used to communicate with a graphics system for displaying position. The method 3 mode of GPS position solution (airborne GPS raw measurements are transmitted to the ground station where they are corrected using the reference receiver corrections and a position solution is calculated on the ground station) was used for real-time operation. Data presented in this report as real time used the algorithms that would have been used on the airborne unit for method 1 processing. These data were processed postmission and are a representation of what the data would have been assuming a perfect transmission data link with no data dropouts. For most applications where there is line of sight between the ground station and the airborne unit, this is a safe assumption.

1.5.3 Although some maneuvers were not completed within the smaller prescribed box inside the optical trackers, all were completed within the larger rectangle formed by the trackers (fig. 2).

1.5.4 The helicopter performed the maneuvers IAW the test plan. These maneuvers were increasingly more dynamic and gave a trend of the effects of the dynamics on the GPS solution.

1.5.5 The constellation of GPS satellites viewable by both the ground station and the airborne GPS varied between 6 and 9. The solution switched between satellites during the dynamic maneuvers, but the transitions occurred without dropping below the 6 common satellites.

1.5.6 The data comparing the postmission and real-time processed GPS position solution to the WSMR optics data are summarized in app C and D, respectively. A summary of statistics for the postmission and real-time processed data is in app E.

## 1.6 CONCLUSIONS

1.6.1 The TDARDS is capable of tracking helicopters through their flight envelope to an accuracy of less than 2 feet SEP in real time. The TDARDS solution can be refined in postmission processing to an accuracy of less than 1 foot SEP. It should be noted that the accuracies stated are dependent on having satellite coverage equivalent to the test data or better.

1.6.2 The rotor system appeared to have minimal effect on the GPS signals. There was no difficulty in signal tracking or acquisition, and there was no appreciable carrier-to-noise loss due to the GPS antenna being located under the rotor.

SECTION 2. APPENDIXES

APPENDIX A. METHODOLOGY INVESTIGATION PLAN AND DIRECTIVE

STEAT-FS-B (70-10r) 13 JUN 1994

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Internal Test Plan (Support), Global Positioning System (GPS), TECOM Project No. 4-CO-210-000-068, XO 399

1. REFERENCES

a. Memorandum, Department of the Air Force, Aeronautical Systems Center, 5 May 1994, subject: Customer Test Request, U.S. Army Aviation Technical Test Center.

b. Telephone Conversation, Mr. Rigler, AMSTE-TA-L, Headquarters, U.S. Army Test and Evaluation Command (HQ TECOM), and Mr. Hamilton, STEAT-TS-P, U.S. Army Aviation Technical Test Center (ATTC), 31 May 1994, subject: Support for GPS Test.

c. Technical Manual (TM) 55-1520-237-10, Operator's Manual for UH-60A through UH-60L Helicopters, 15 February 1993.

2. TEST OBJECTIVES

Support the helicopter GPS test program conducted by the Eglin Air Force Base (AFB), Florida (FL), Range Applications Joint Program Office (RAJPO) to:

a. Quantify the effect of rotor blade interference with GPS receiver operation.

b. Determine a suggested location of the GPS antenna for future helicopter use.

3. TESTING AUTHORITY

a. On 5 May 1994, the U.S. Air Force (USAF) Aeronautical Systems Center requested HQ TECOM to direct ATTC to support the Eglin AFB RAJPO as required for the GPS test (reference (ref) paragraph (para) 1a).

b. On 31 May 1994, HQ TECOM directed ATTC to support the GPS test as requested (ref 1b).

4. SYSTEM DESCRIPTION

The instrumentation to be installed on the UH-60A consists of the GPS Coarse Acquisition Code Receiver (CACR), a GPS antenna, a High Dynamics Instrumentation System (HDIS) GPS receiver with solid-state recorder, a RAJPO Data Link System (DLS), a DLS antenna, and a radar tracking transponder and antenna.

5. TEST CONCEPT/PROCEDURE

a. The flight testing will be conducted at Eglin AFB, FL, from 13 June to approximately 17 June 1994. One UH-60A helicopter will be ferried from Cairns Army Airfield (AAF), Fort Rucker, Alabama (AL), to Eglin AFB, FL. Upon arrival at Eglin AFB, the test equipment for the GPS project will be ground checked. DynCorp will provide aircraft staging and maintenance support at Eglin AFB which is several miles from the test site at Eglin range B70.

b. The test will be conducted in approximately 6 flight-hours under day visual meteorological conditions (VMC). Ferry flights to and from the test site (if required) may be completed during day or night VMC or instrument meteorological conditions (early takeoffs and late returns).

c. The flight portion of the test will be conducted at the Eglin AFB test range. The profiles consist of standard maneuvers, shown in table 1, in a specified area of the range. As the helicopter flies the profiles and GPS signal data are acquired and recorded, cinetheodolites and ground-based range radars will track the helicopter location and provide truth data.

Table 1. Flight Maneuvers for GPS Test

| MANEUVERS | Altitudes (ft AGL) | Airspeed (KIAS) | Bank Angle (Deg) | Load Factor (g) |
|---|---|---|---|---|
| 1. Racetrack | 500 | 70 | 30-45 | <2.0 |
| 2. Figure-8 | 500 | 70 | 30-45 | <2.0 |
| 3. Vertical takeoff (100-ft increments) | 500 | TBD | 0 | <2.0 |
| 4. Maximum vertical climb | 500 | TBD | 0 | <2.0 |
| 5. Medium vertical climb | 500 | TBD | 0 | <2.0 |
| 6. High speed run | 500 | 120-130 | 0 | <2.0 |
| 7. Rapid altitude change in flight | 100-300 | 100-110 | 0 | <2.0 |

| | |
|---|---|
| Notes: | AGL - above ground level<br>Deg - degrees<br>ft - feet<br>g - gravity<br>KIAS - knots indicated airspeed<br>TBD - to be determined |

6. ADMINISTRATION AND SUPPORT REQUIREMENTS

a. ATTC will provide one UH-60 helicopter and flightcrew.

b. DynCorp will provide maintenance support at Eglin AFB and Cairns AAF as required. If this test is done on a TDY basis, the DynCorp support crew will consist of a flight mechanic, an electrician, and a technical inspector.

c. The 46th Test Wing (46TW) at Eglin AFB will provide test management and coordination of the overall test effort.

d. The test equipment suite (para 4) will be provided by RAJPO and installed by Dyncorp technicians at Cairns AAF. ATTC will conduct flight release inspections and provide a flight release for the internal sensor package installation.

e. USAF personnel and contractor personnel from Eglin AFB will be flying in the aircraft during the test as test instrumentation operators.

f. The aircraft will be flown without the external stores support system. Crew will consist of two pilots, one crew chief, and up to two instrumentation technicians. With the test equipment installed, the takeoff gross weight will be approximately 15,000 pounds.

g. The aircraft will be flown within the limitations of the UH-60 Operator's Manual (ref 1c) and the flight release.

h. Labor and flight-hours will be charged to XO 399.

i. ATTC will submit a test record within 35 days of test completion.

j. The overall level of risk for this test support is LOW (III-E).

STEAT-FS-B
SUBJECT: Internal Test Plan (Support), Global Positioning System (GPS), TECOM Project No. 4-CO-210-000-068, XO 399

7. POINT OF CONTACT

Point of contact is CW5 William R. Murphy, Test Director, DSN 558-8167, commercial (205) 255-8167, or FAX (205) 255-8174, Fort Rucker.

FOR THE COMMANDER:

JOHN V.R. REDINGTON
LTC, AV
Director, Flt Sys Test Directorate

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REPLY TO ATTENTION OF

AMSTE-CT-T (70-10p)

MEMORANDUM FOR Commander, U.S. Army Aviation Technical Test Center, ATTN: STEAT-TS-P, Fort Rucker, AL 36362-5276

SUBJECT: Amendment 2 to Test Execution Directive, FY95 Methodology Program

1. Reference HQ TECOM Memo, AMSTE-CT-T, 12 Sep 94, subject: Test Execution Directive, FY95 Methodology Program.

2. This memorandum, with list of projects at enclosure 1, amends reference 1.

3. Point of contact at this headquarters is Ms. Cyndie McMullen, AMSTE-CT, amstect@apg-9.apg.army.mil, DSN 298-1469.

FOR THE COMMANDER:

Encl

FREDERICK D. MABANTA
Chief, Technology Development Division
Directorate for Corporate Information
and Technology

CF:
Cdr, USAATTC, ATTN: STEAT-TS-D (Larry Eagerton)

FY95 METHODOLOGY PROGRAM

## AVIATION TECHNICAL TEST CENTER

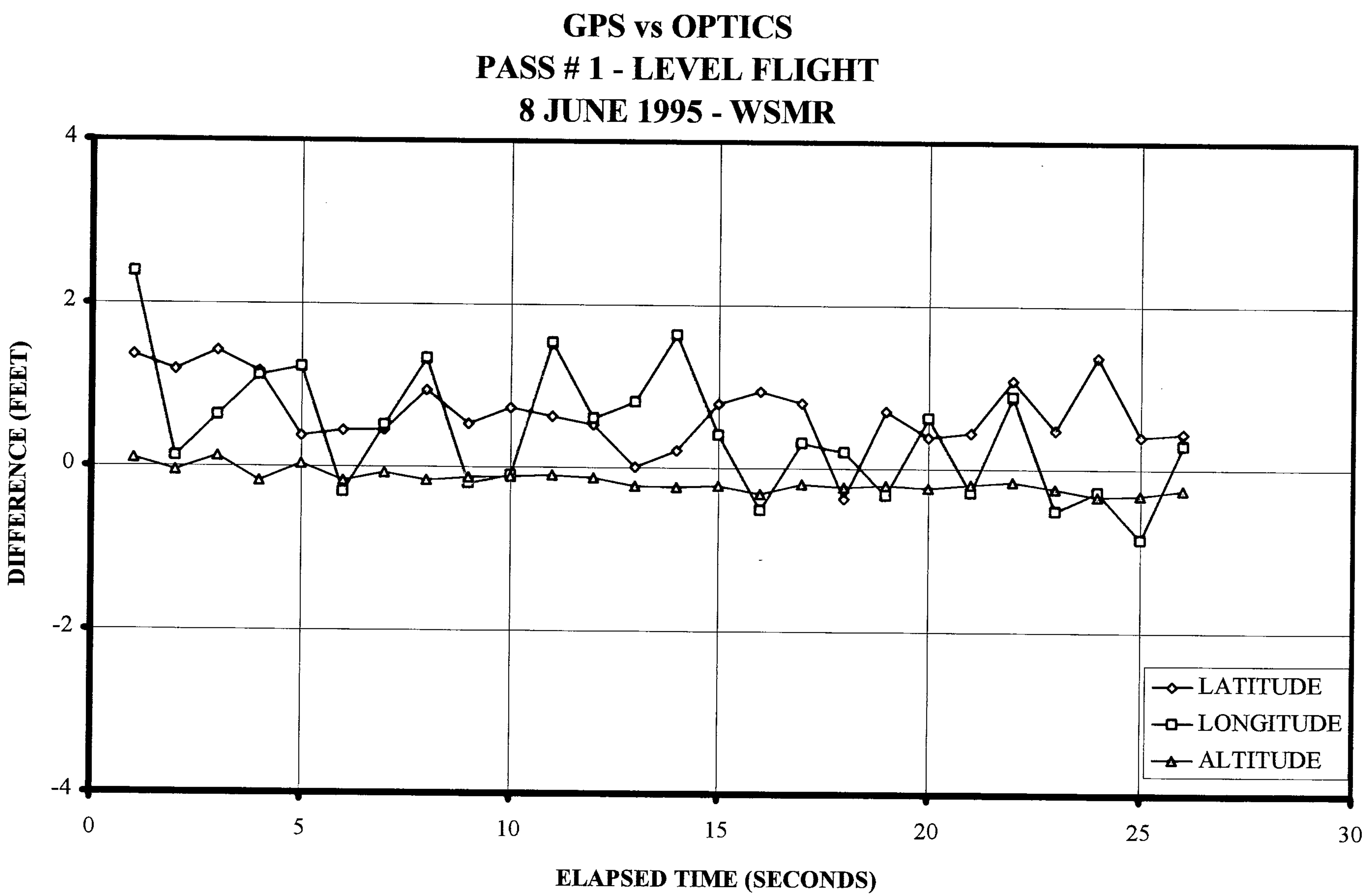
| | | INITIAL FUNDING | REVISED FUNDING | AMEND #1 24JAN95 | AMEND #2 15JUN95 |
|---|---|---|---|---|---|
| 7-CO-M95-AVD-001 | FY95 Quick Reaction Methodology | 20.0 | 5.0 | -15.0 | 0.0 |
| 7-CO-M95-AVD-002 | FY95 Technical Committee Support | 5.0 | 5.0 | 0.0 | 0.0 |
| 7-CO-M95-AVD-003 | Common Airborne Instrumentation Testing | 100.0 | 0.0 | -100.0 | 0.0 |
| 7-CO-M95-AVD-004 | GPS System Investigation | 0.0 | 80.0 | 65.0 | 15.0 |
| | | ---- | ---- | --- | --- |
| | TOTAL ATTC PROGRAM | 125.0 | 90.0 | -50.0 | 15.0 |

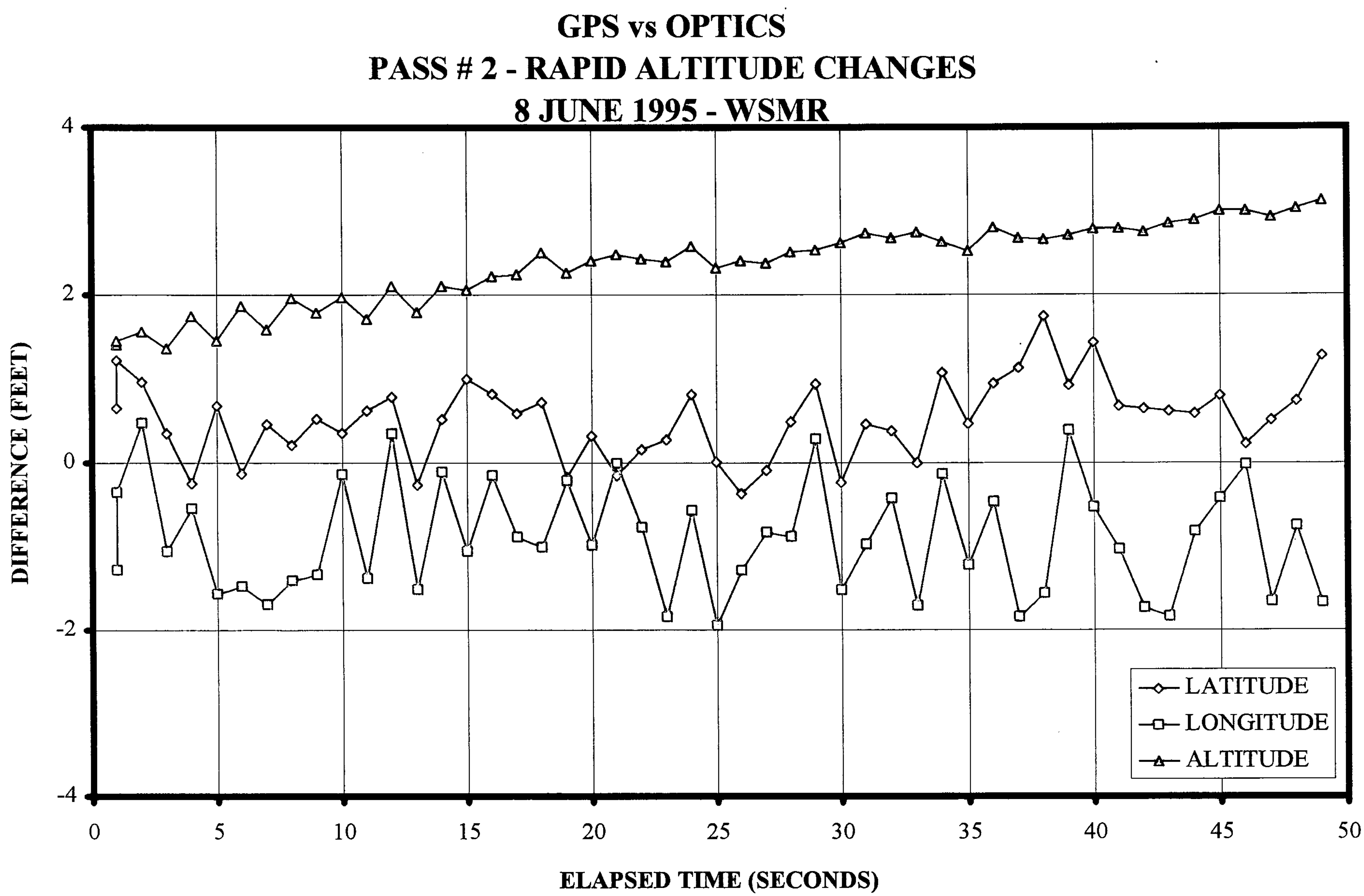
## APPENDIX B. START AND STOP TIMES

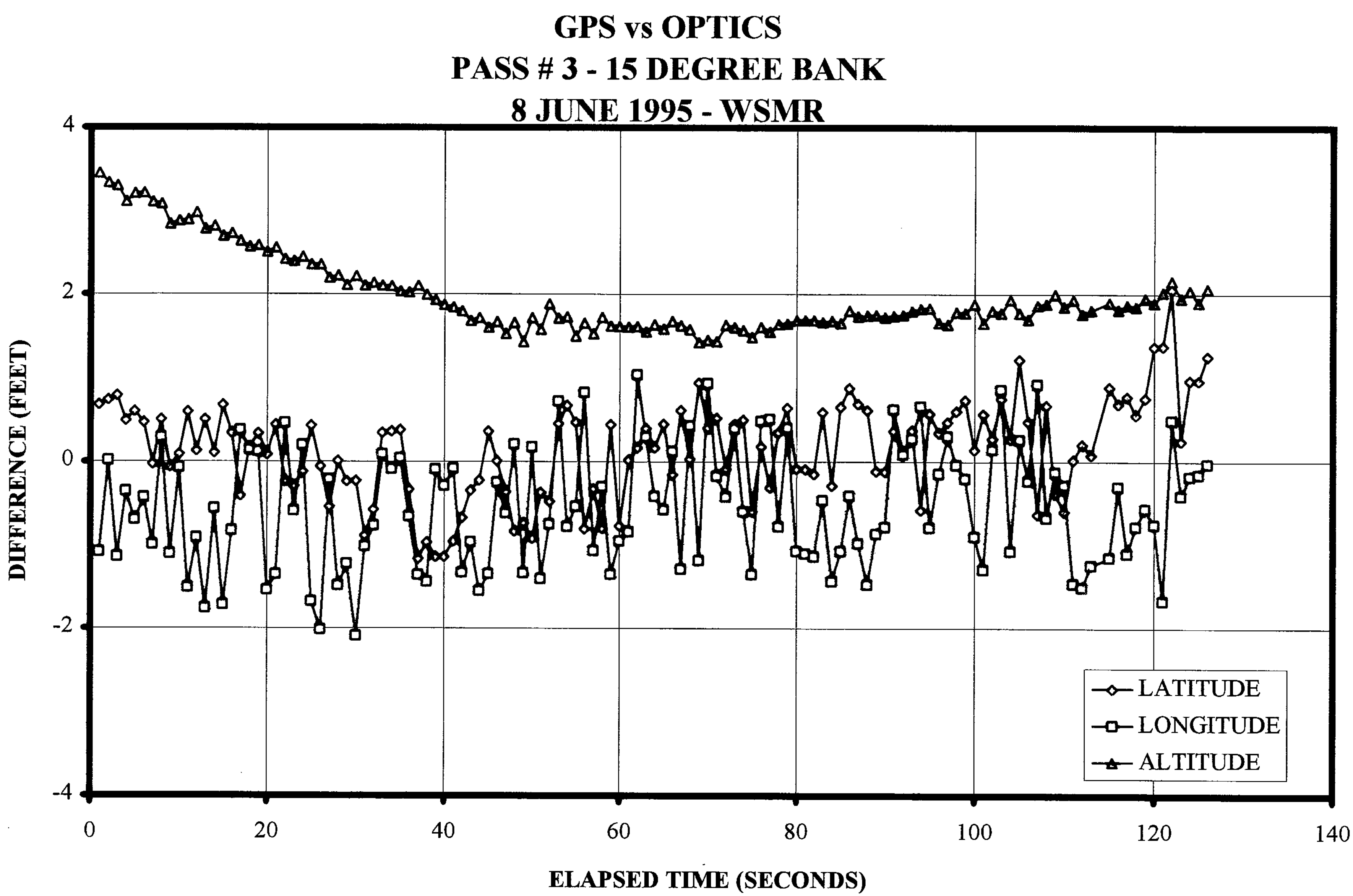
Following are the start and stop times (Greenwich mean time (GMT)) for each data pass on 8 June 1995. Times are shown in the following sequence: Julian date:hours:minutes:seconds.

| PASS | MANEUVER | START | END |
|---|---|---|---|
| 1 | Level Flight | 5159:18:18:50 | 5159:18:19:17 |
| 2 | Rapid Altitude Change | 5159:18:20:21 | 5159:18:21:12 |
| 3 | 15° Bank | 5159:18:23:14 | 5159:18:25:21 |
| 4 | 30° Bank | 5159:18:26:34 | 5159:18:28:10 |
| 5 | 45° Bank | 5159:18:29:22 | 5159:18:30:40 |
| 6 | 60° Bank | 5159:18:31:48 | 5159:18:32:53 |
| 7 | Figure 8 | 5159:18:34:12 | 5159:18:36:00 |
| 8 | Level Flight | 5159:18:37:16 | 5159:18:37:48 |
| 9 | Rapid Altitude Change | 5159:18:39:13 | 5159:18:39:51 |
| 10 | Level Flight | 5159:18:41:16 | 5159:18:41:43 |
| 11 | 15° Bank | 5159:18:43:12 | 5159:18:44:55 |
| 12 | 30° Bank | 5159:18:46:48 | 5159:18:48:05 |
| 13 | 45° Bank | 5159:18:49:47 | 5159:18:50:47 |
| 14 | 60° Bank | 5159:18:52:02 | 5159:18:53:00 |
| 15 | Figure 8 | 5159:18:54:11 | 5159:18:55:09 |
| 16 | Level Flight | 5159:18:57:02 | 5159:18:57:29 |
| 17 | Rapid Altitude Change | 5159:18:59:15 | 5159:18:59:58 |
| 18 | Level Flight | 5159:19:01:34 | 5159:19:02:03 |
| 19 | 15° Bank | 5159:19:04:31 | 5159:19:06:19 |
| 20 | 30° Bank | 5159:19:08:20 | 5159:19:09:41 |

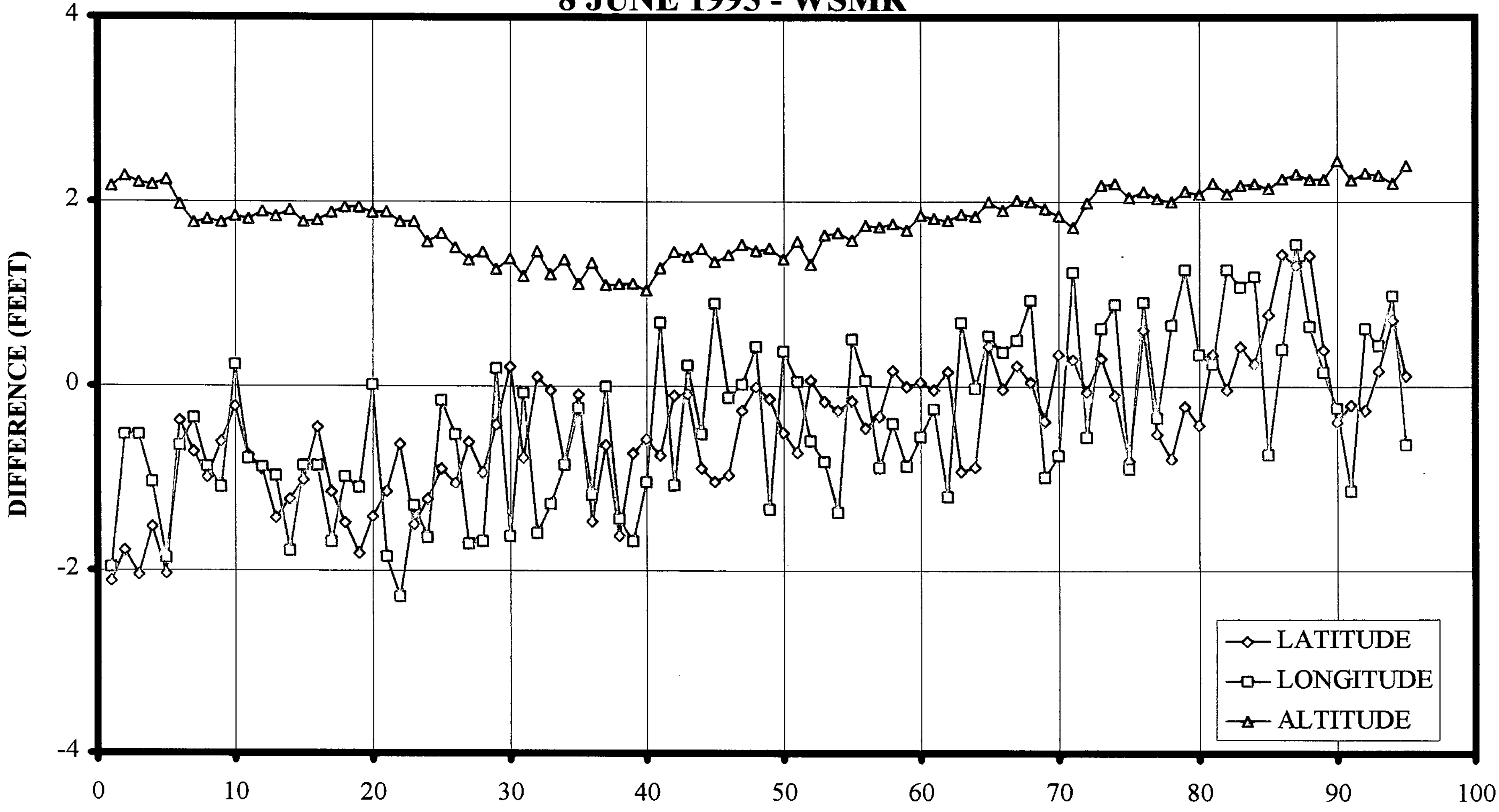
# APPENDIX C. COMPARISON OF POSTMISSION GPS POSITION SOLUTION TO WSMR OPTICS DATA

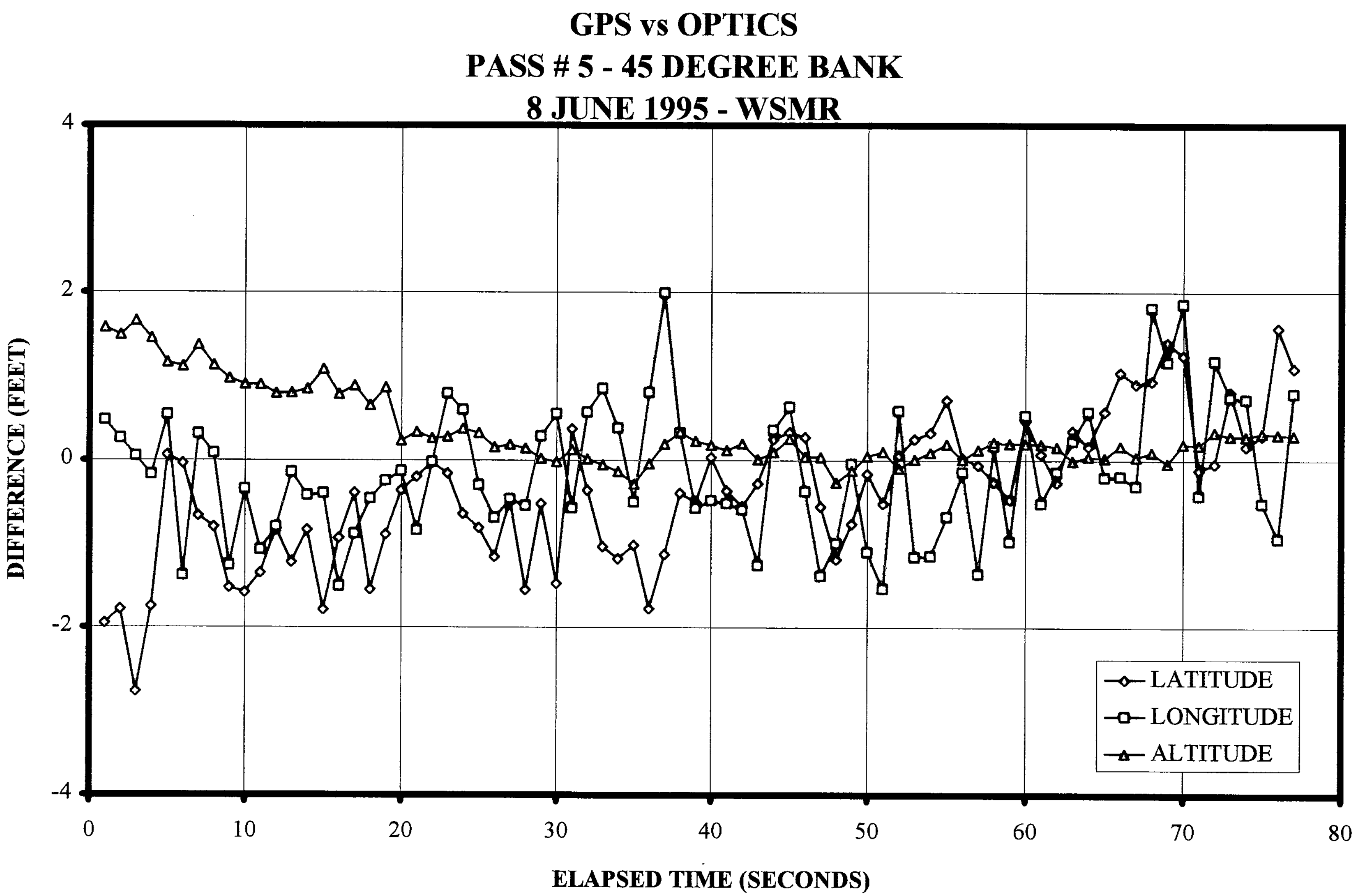

GPS vs OPTICS
PASS # 1 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE


GPS vs OPTICS
PASS # 2 - RAPID ALTITUDE CHANGES
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
35
40
45
50
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

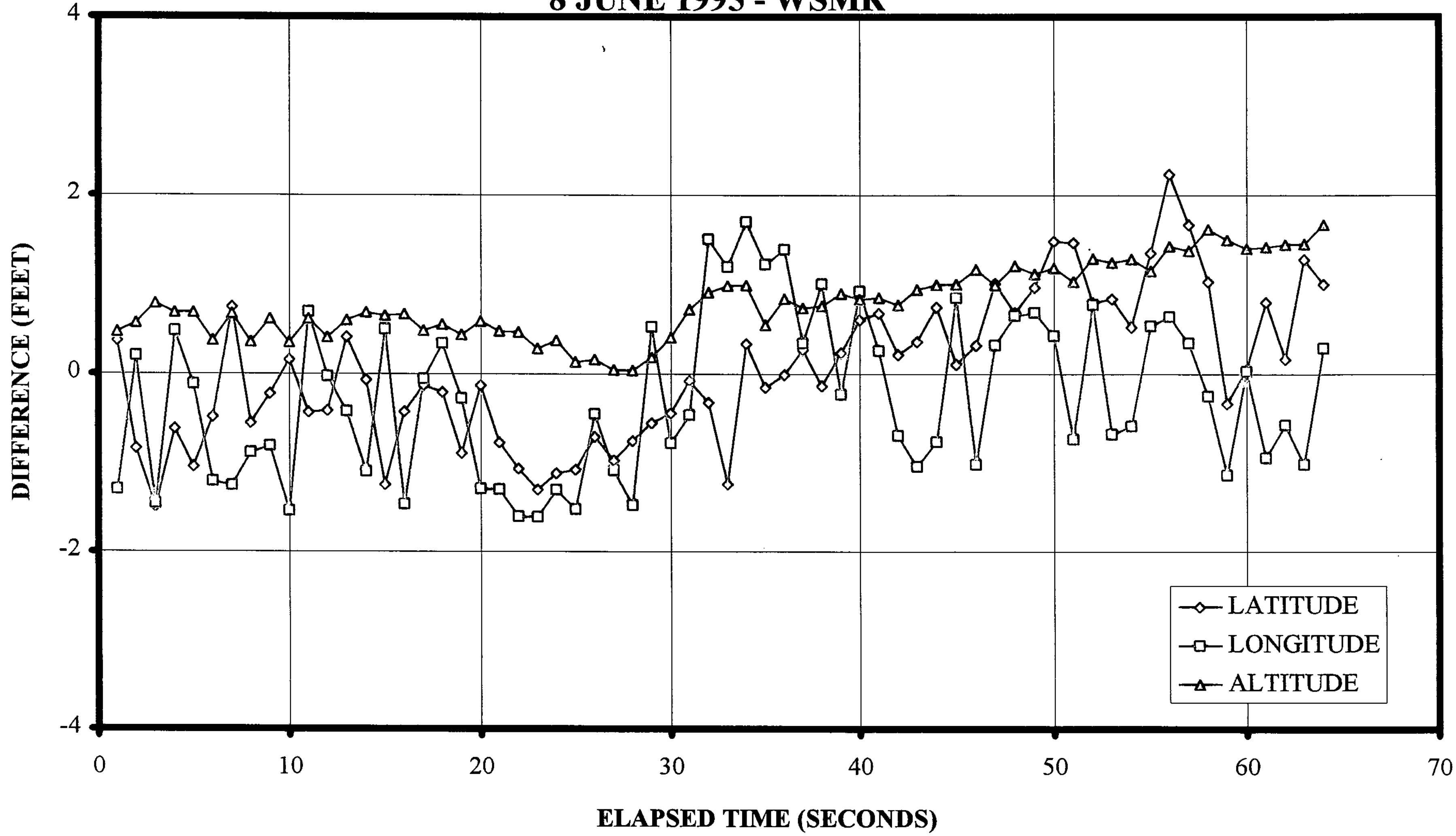

GPS vs OPTICS
PASS # 3 - 15 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
20
40
60
80
100
120
140
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

## GPS vs OPTICS
## PASS # 4 - 30 DEGREE BANK
## 8 JUNE 1995 - WSMR

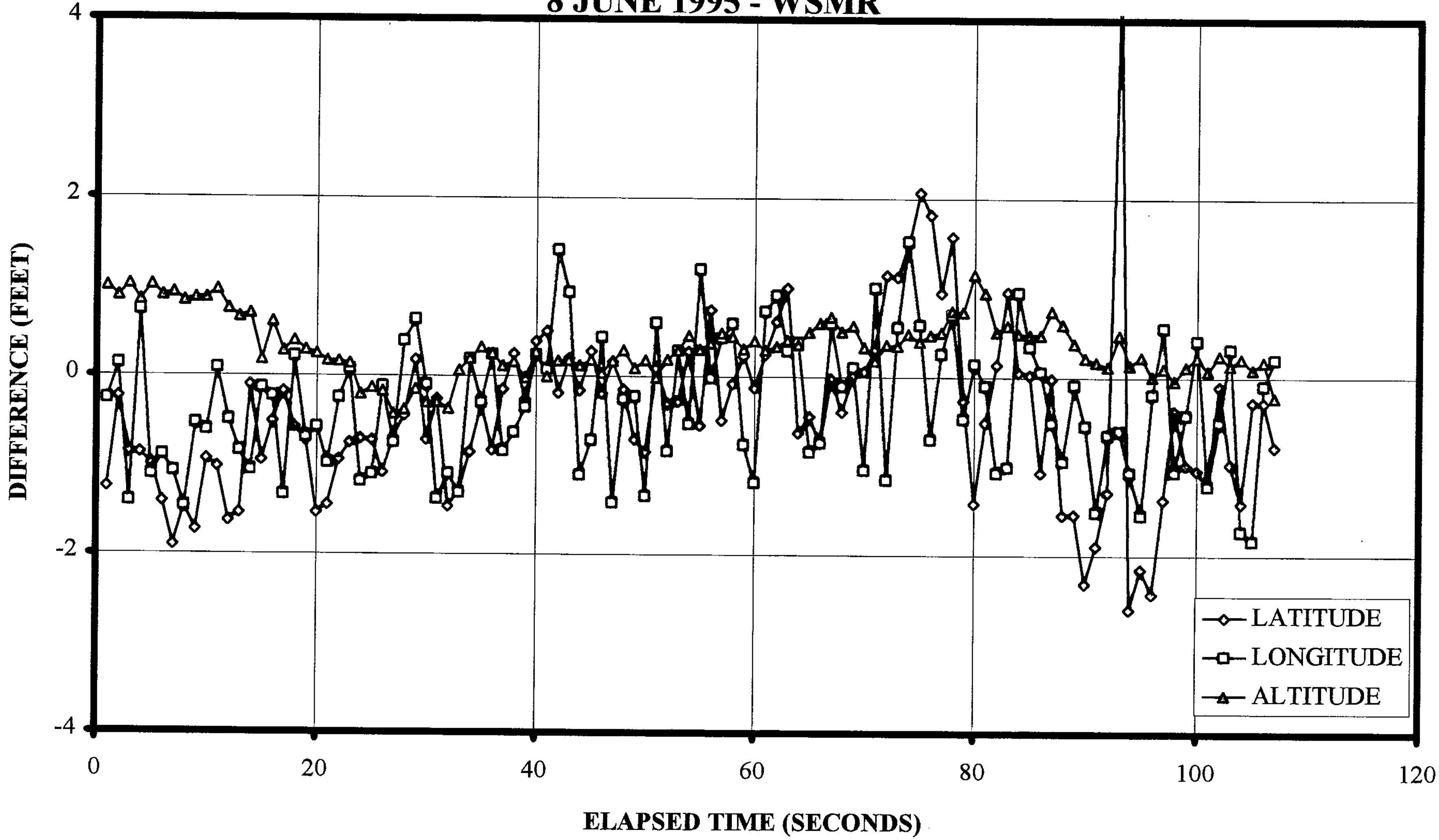


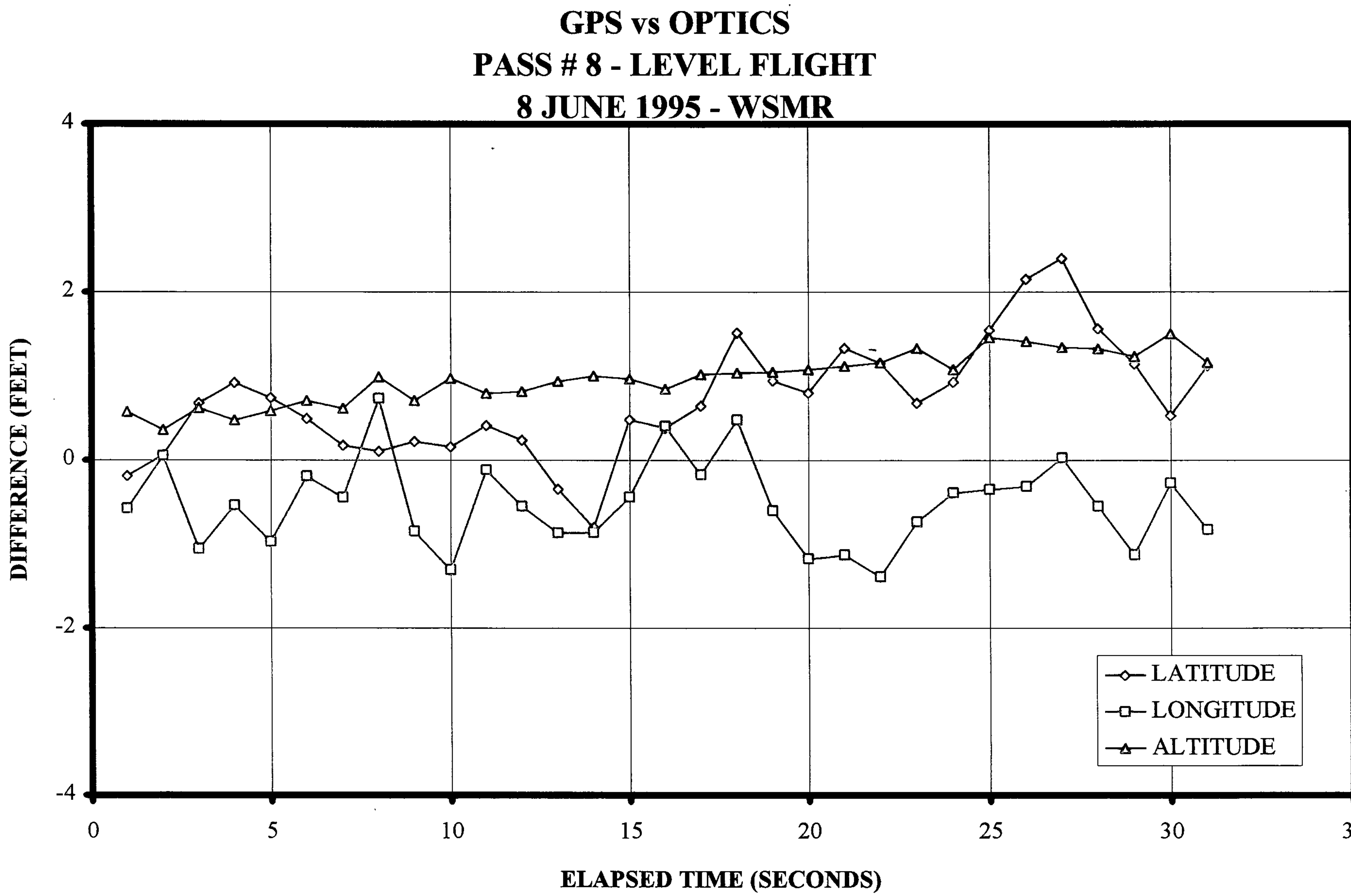

GPS vs OPTICS
PASS # 5 - 45 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

**GPS vs OPTICS**
**PASS # 6 - 60 DEGREE BANK**
**8 JUNE 1995 - WSMR**



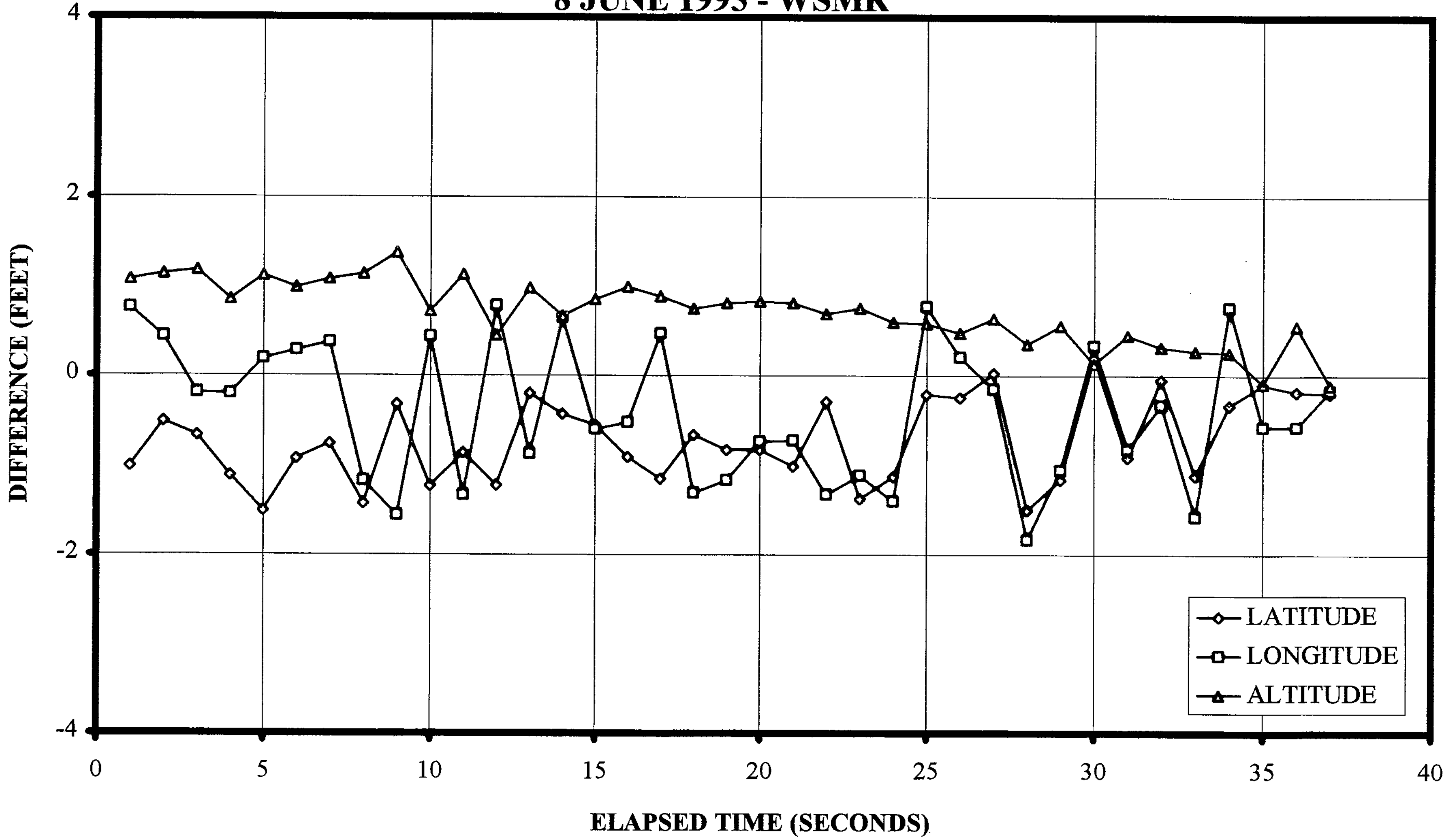
## GPS vs OPTICS
## PASS # 7 - FIGURE EIGHT
## 8 JUNE 1995 - WSMR

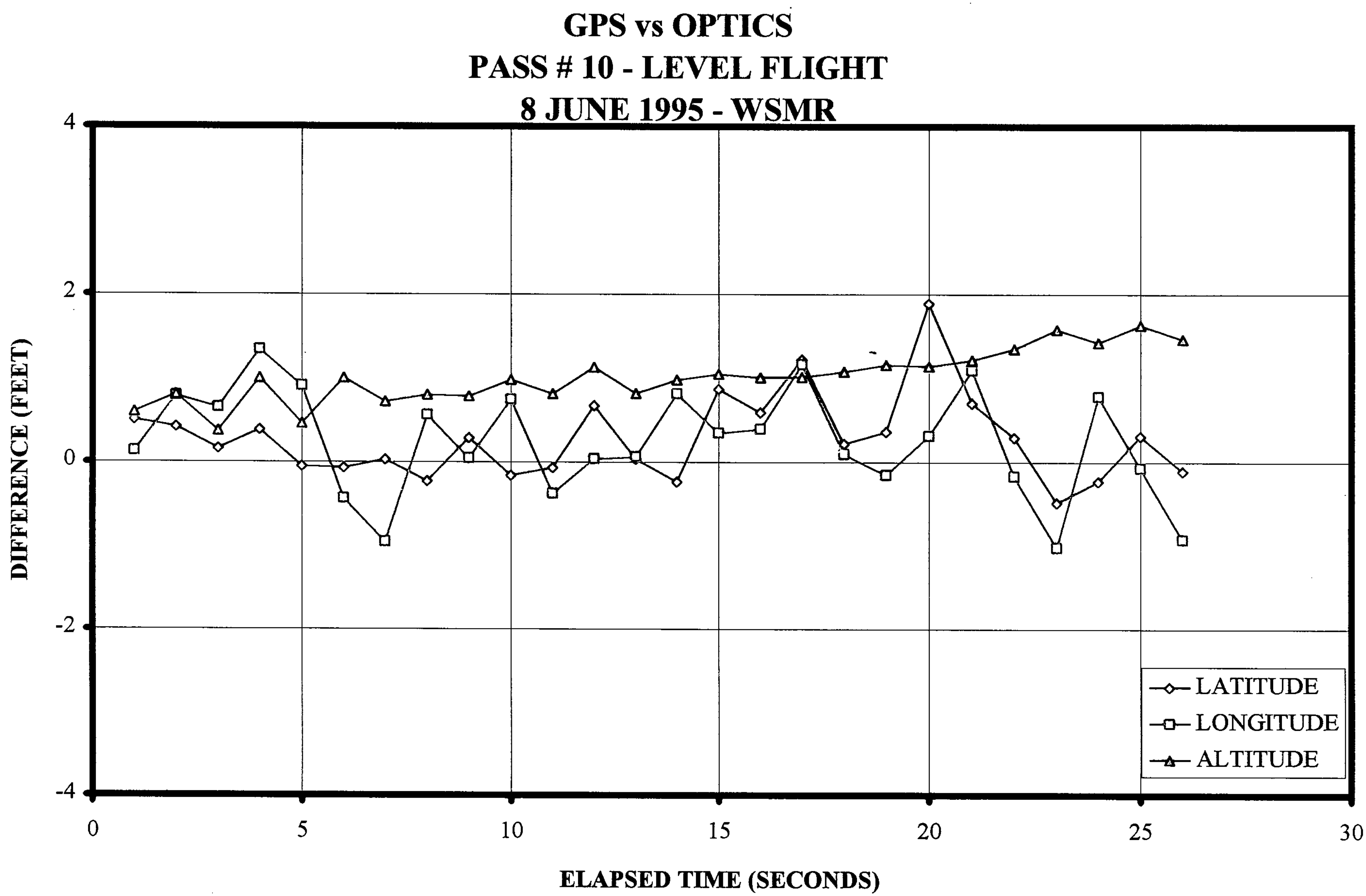


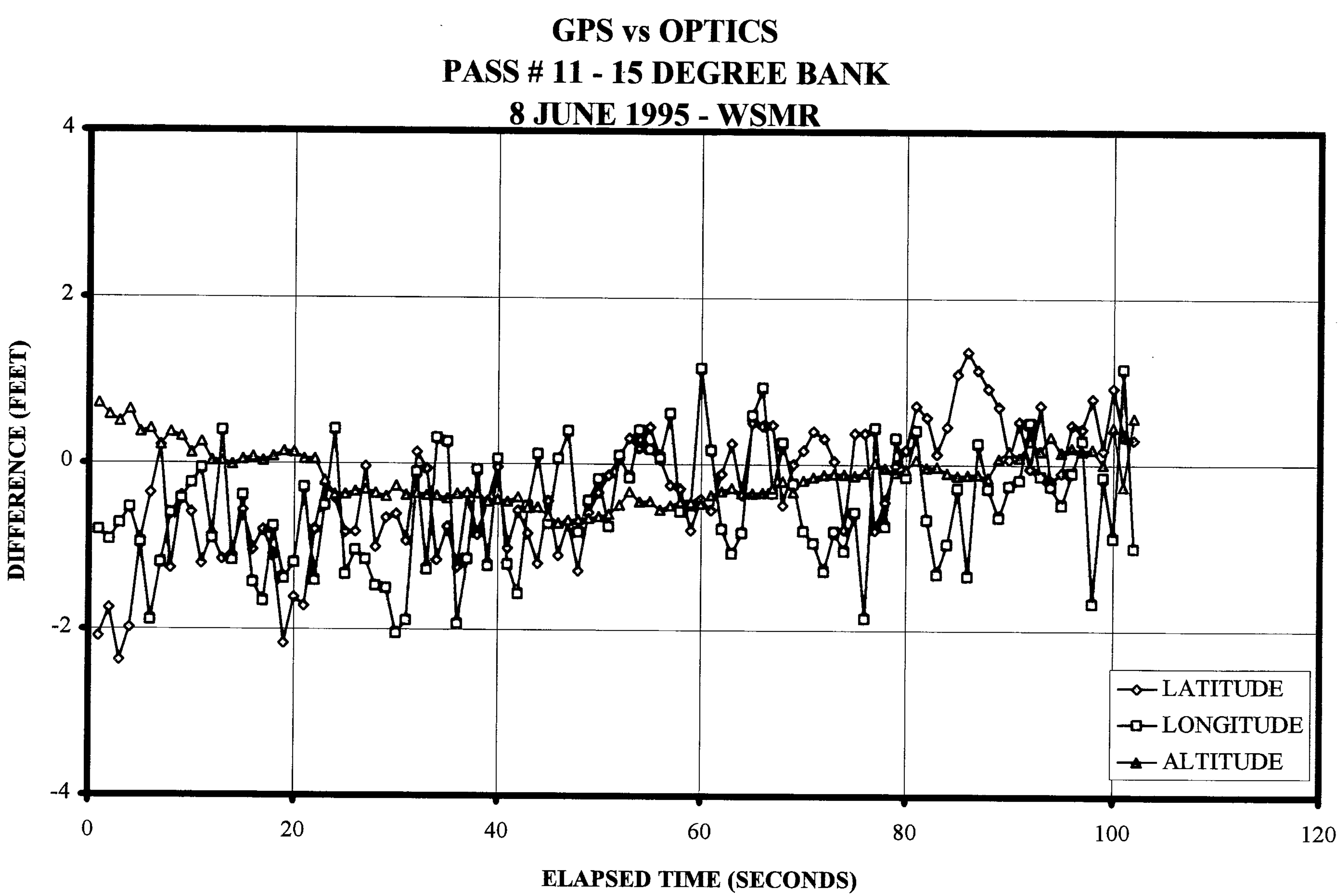


GPS vs OPTICS
PASS # 8 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
35
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

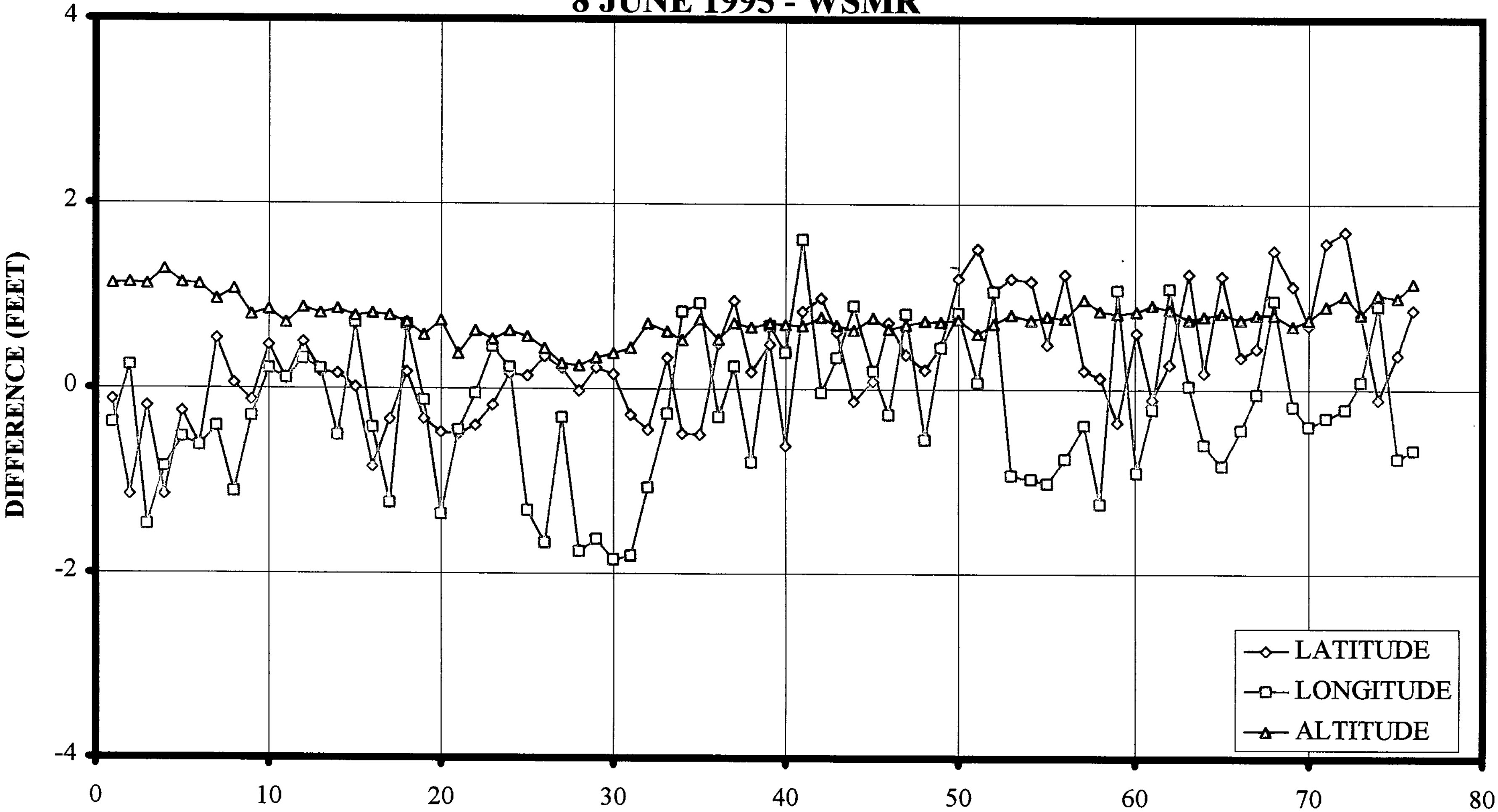
## GPS vs OPTICS
## PASS # 9 - RAPID ALTITUDE CHANGES
## 8 JUNE 1995 - WSMR

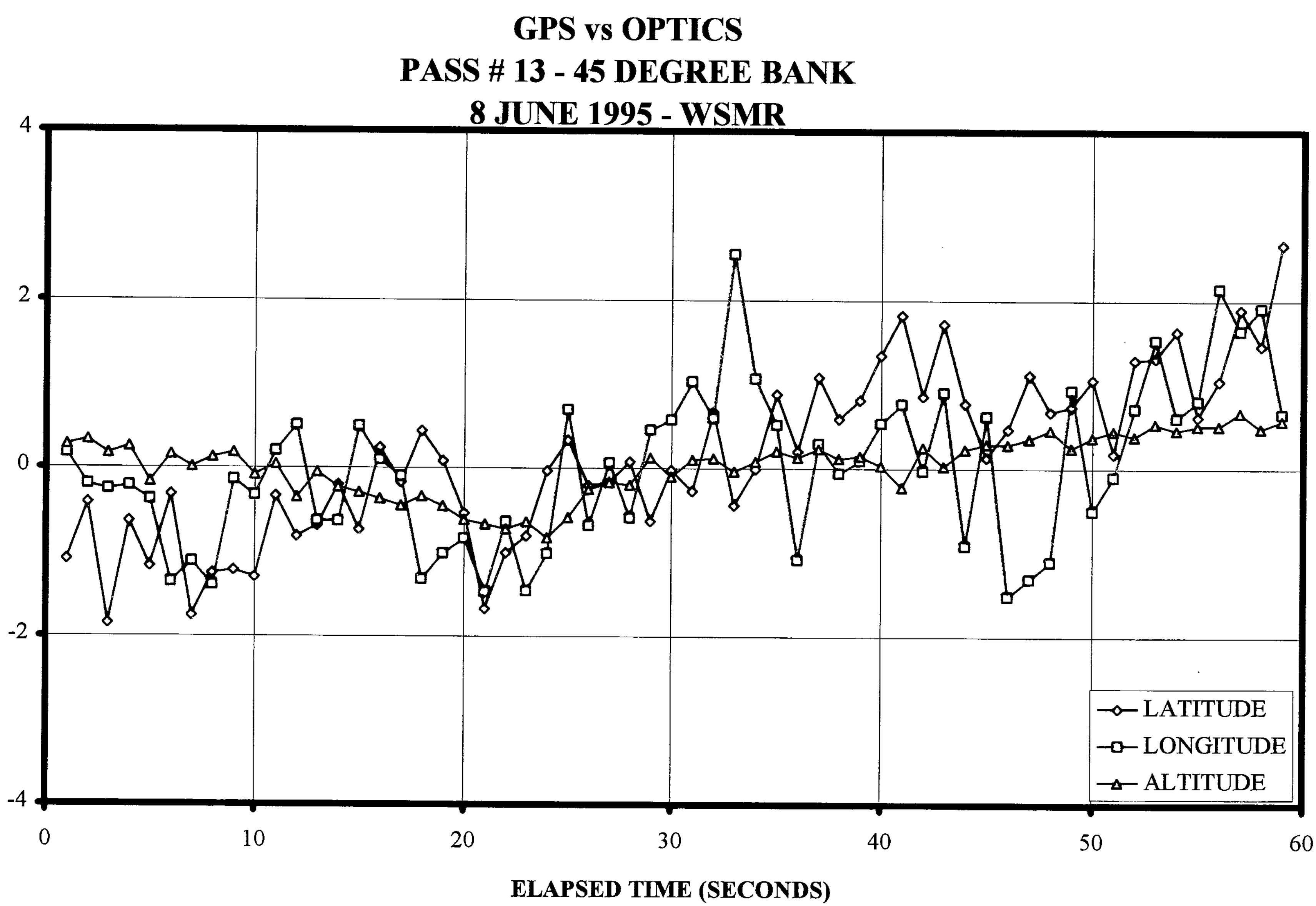



GPS vs OPTICS
PASS # 10 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

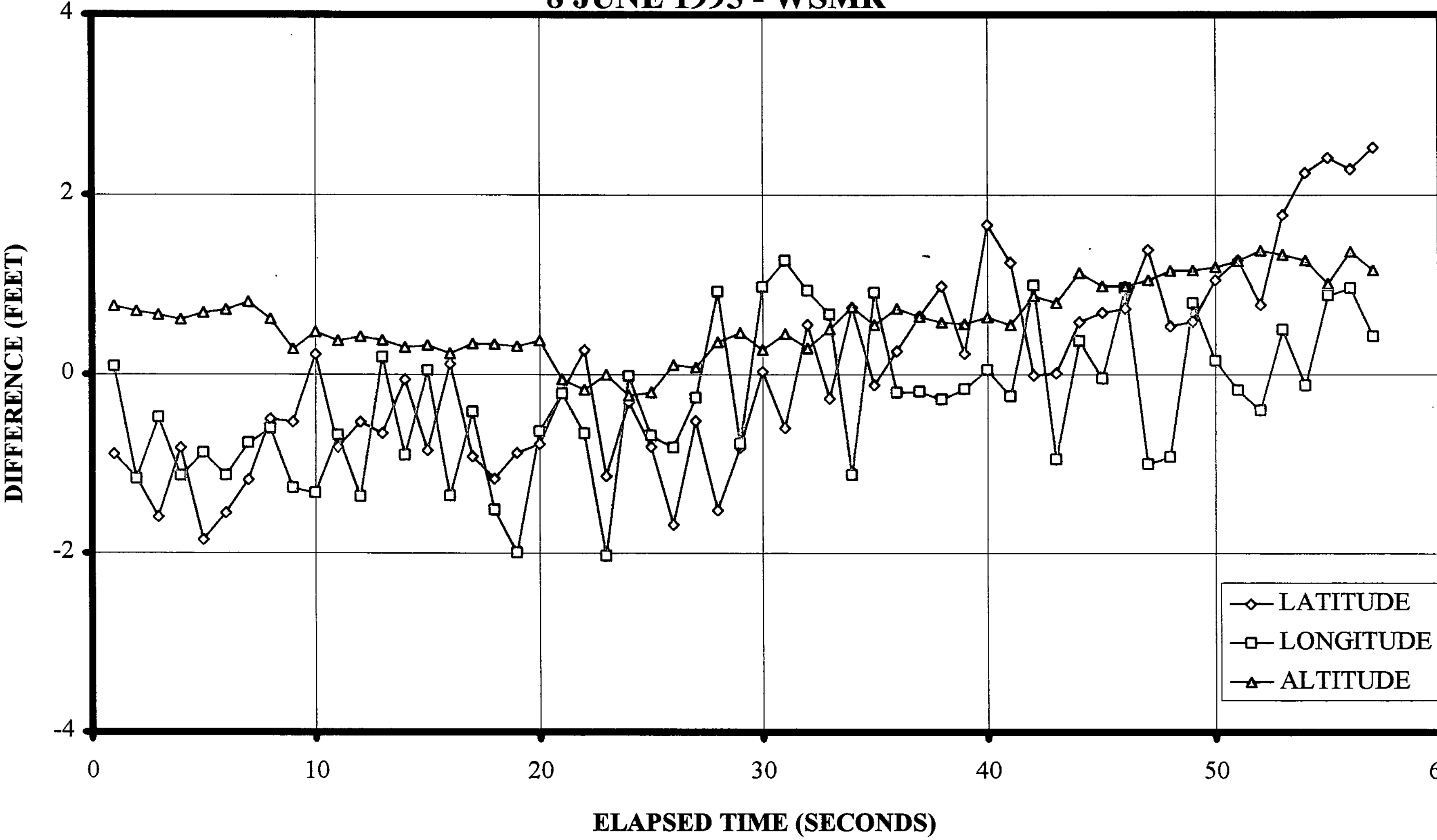

GPS vs OPTICS
PASS # 11 - 15 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
20
40
60
80
100
120
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

## GPS vs OPTICS
## PASS # 12 - 30 DEGREE BANK
## 8 JUNE 1995 - WSMR

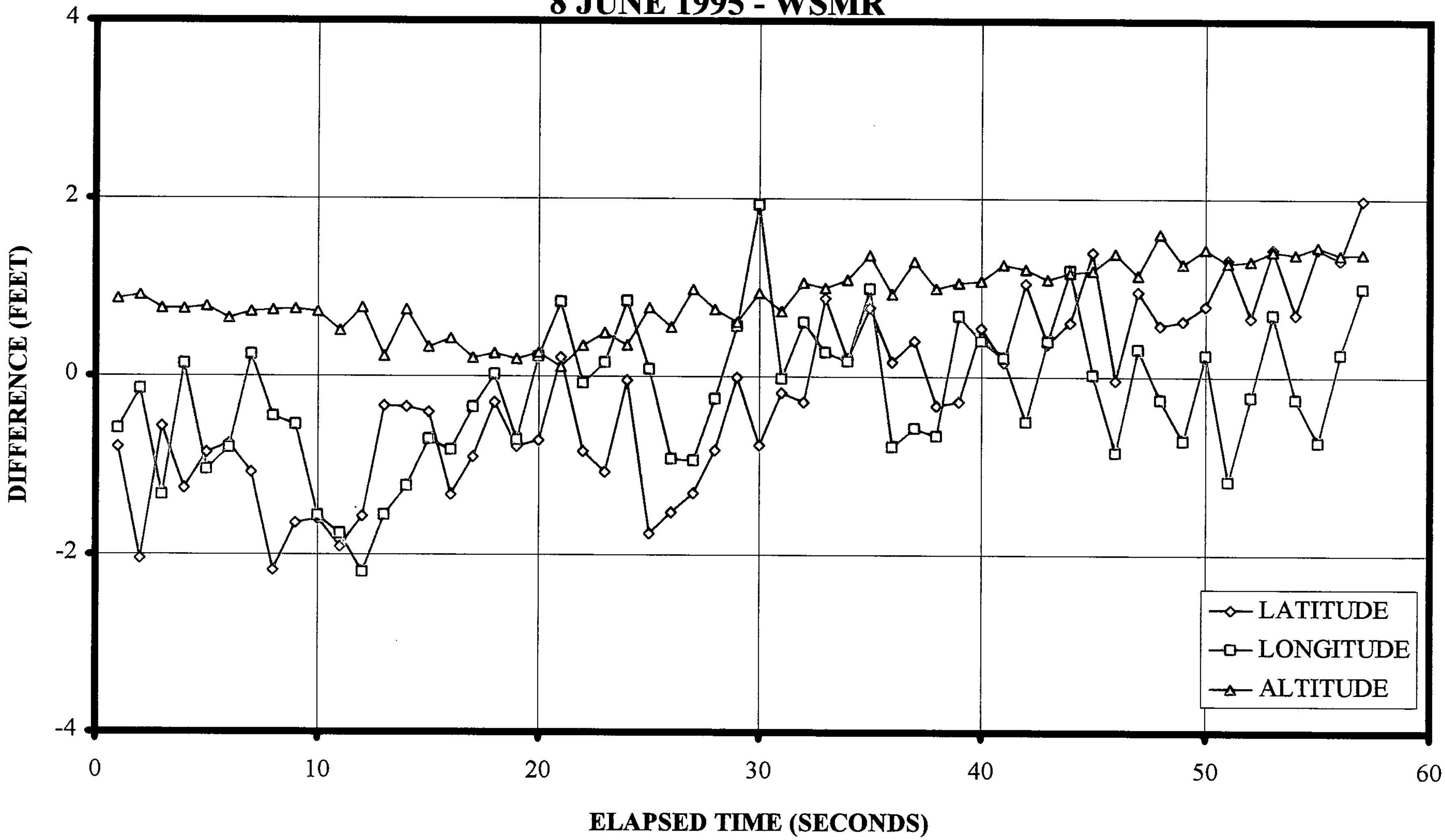



GPS vs OPTICS
PASS # 13 - 45 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

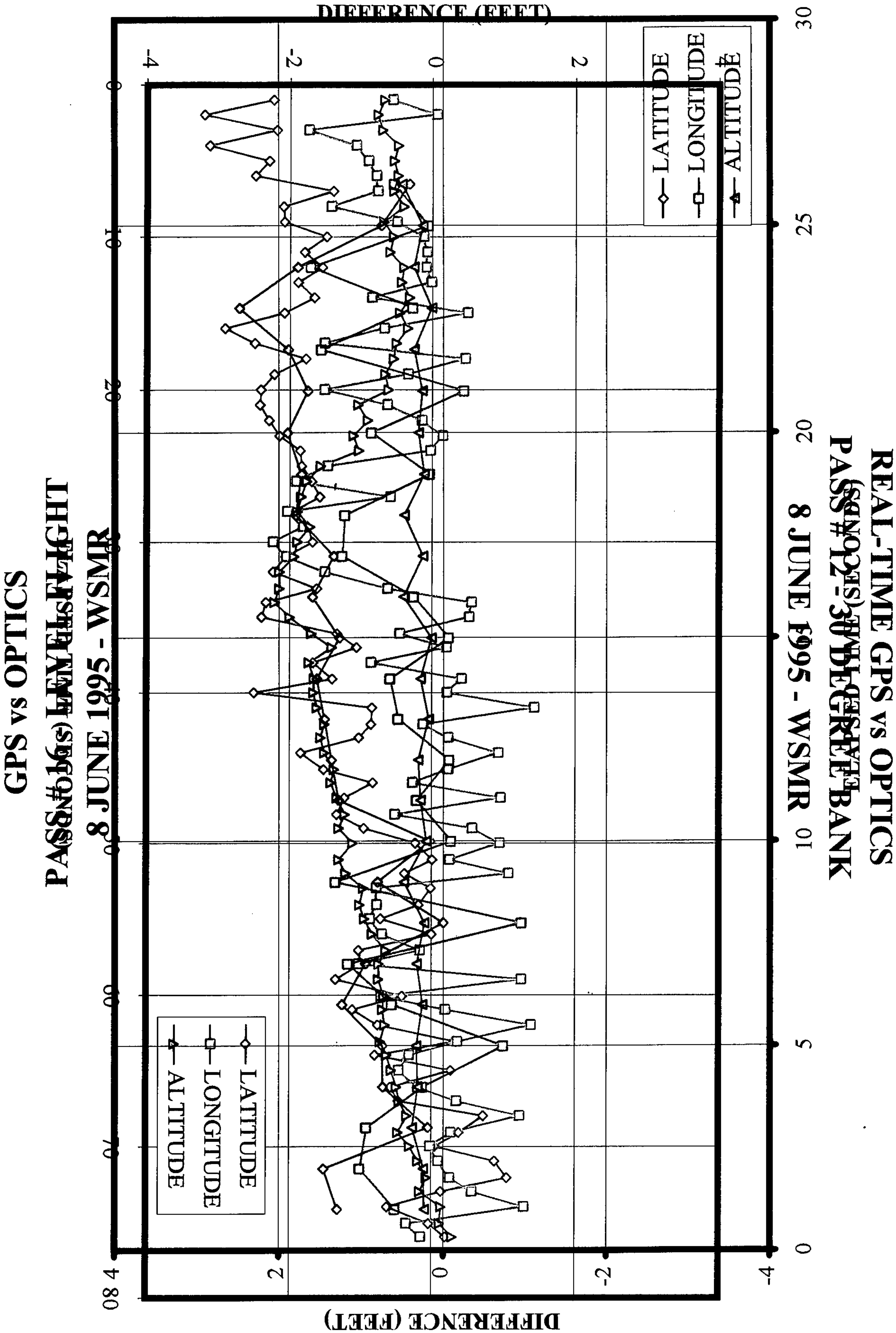
# GPS vs OPTICS
# PASS # 14 - 60 DEGREE BANK
# 8 JUNE 1995 - WSMR



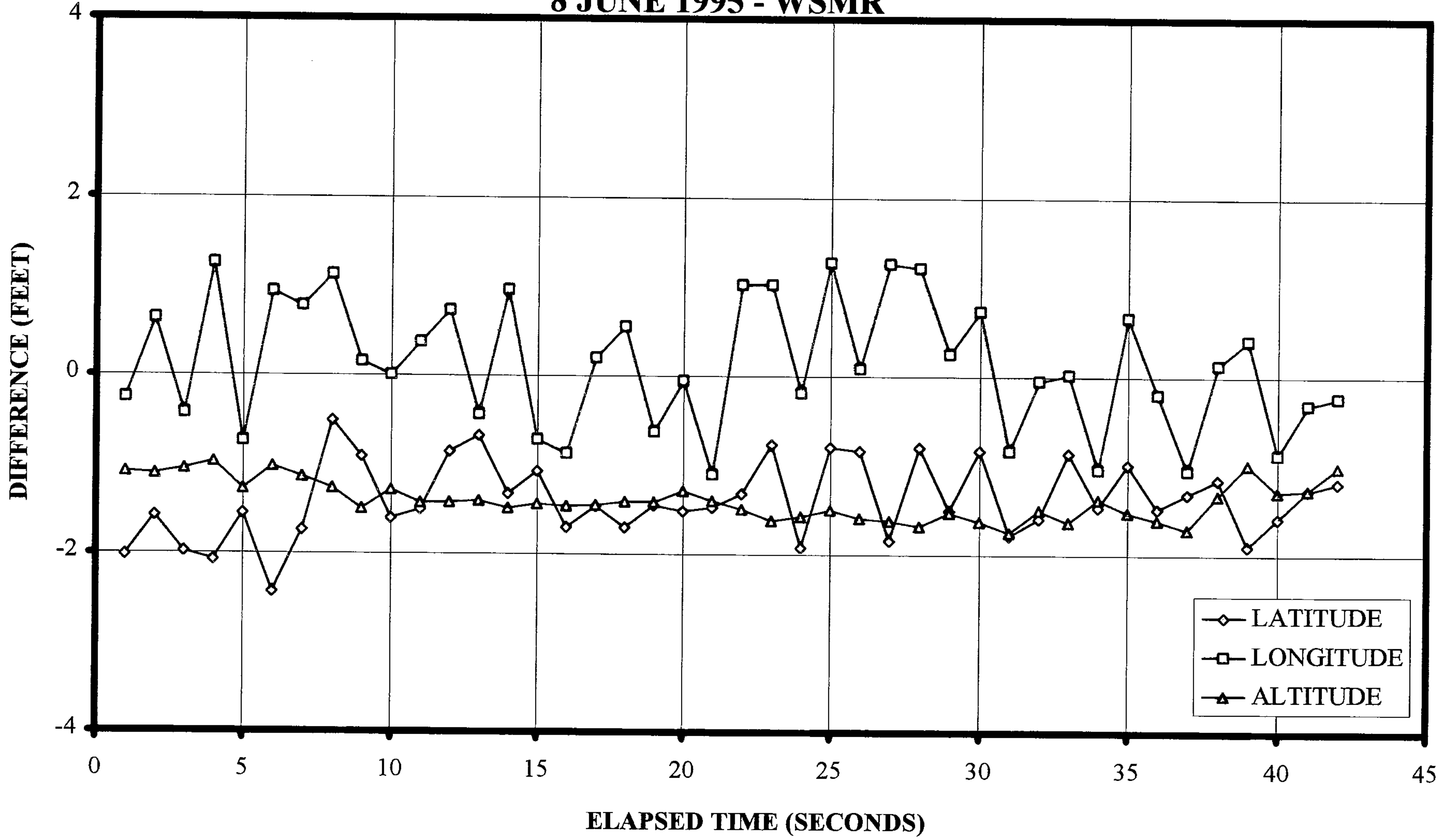
## GPS vs OPTICS
## PASS # 15 - FIGURE EIGHT
## 8 JUNE 1995 - WSMR

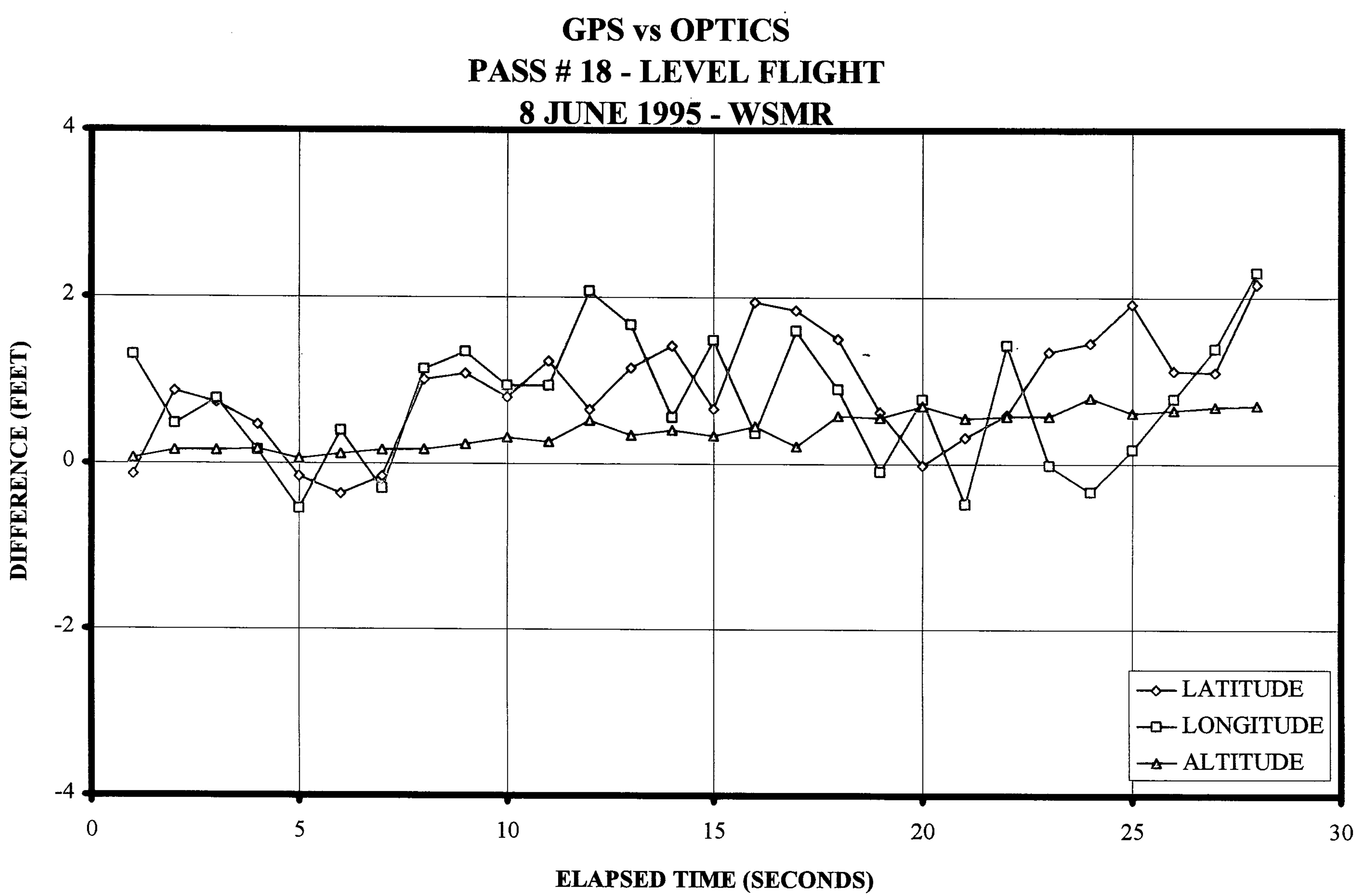


D-14

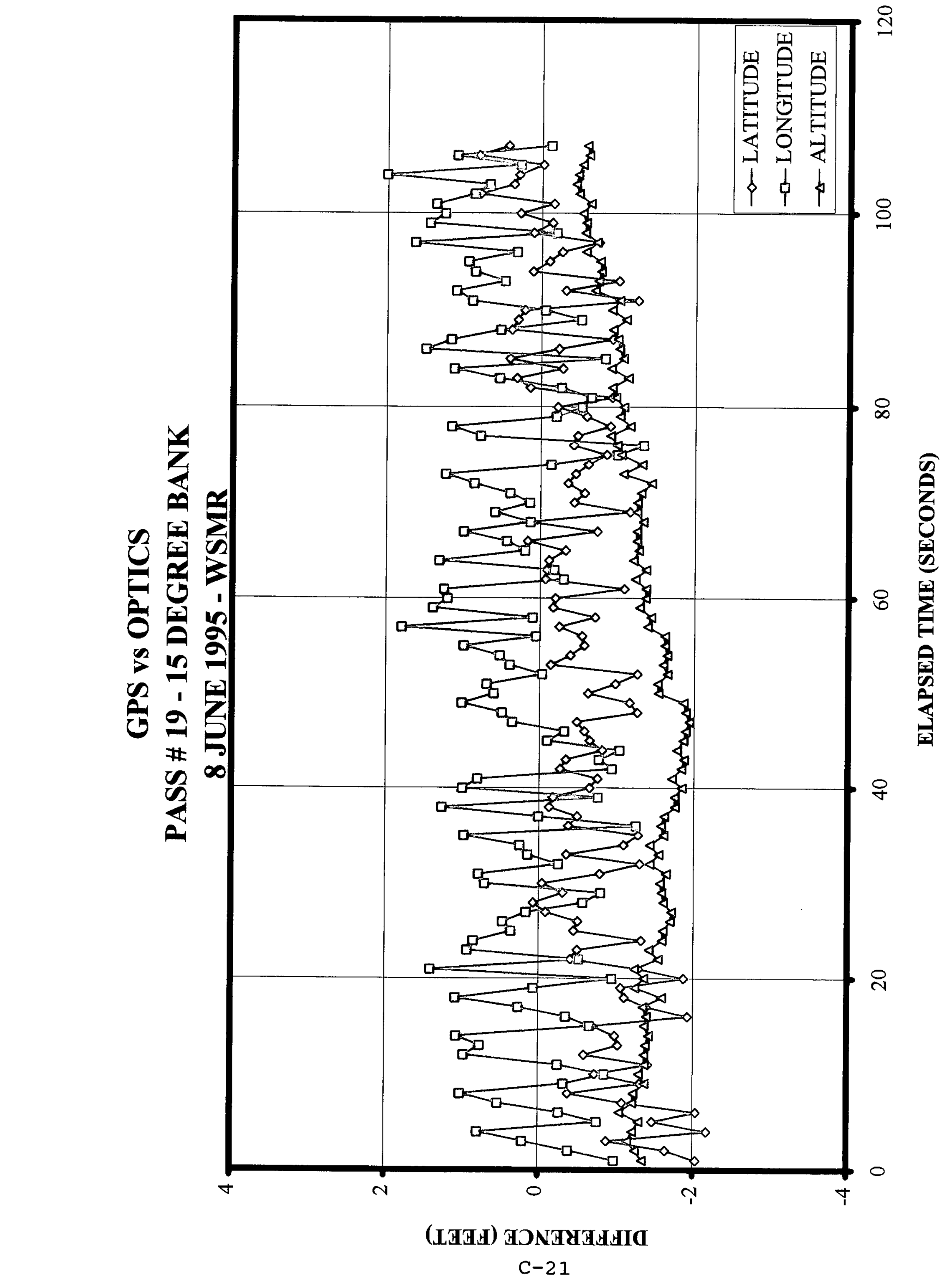

GPS vs OPTICS
PASS #16 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
REAL-TIME GPS vs OPTICS
PASS #12 - 30 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
TIME (secs)
LATITUDE
LONGITUDE
ALTITUDE

## GPS vs OPTICS
## PASS # 17 - RAPID ALTITUDE CHANGES
## 8 JUNE 1995 - WSMR

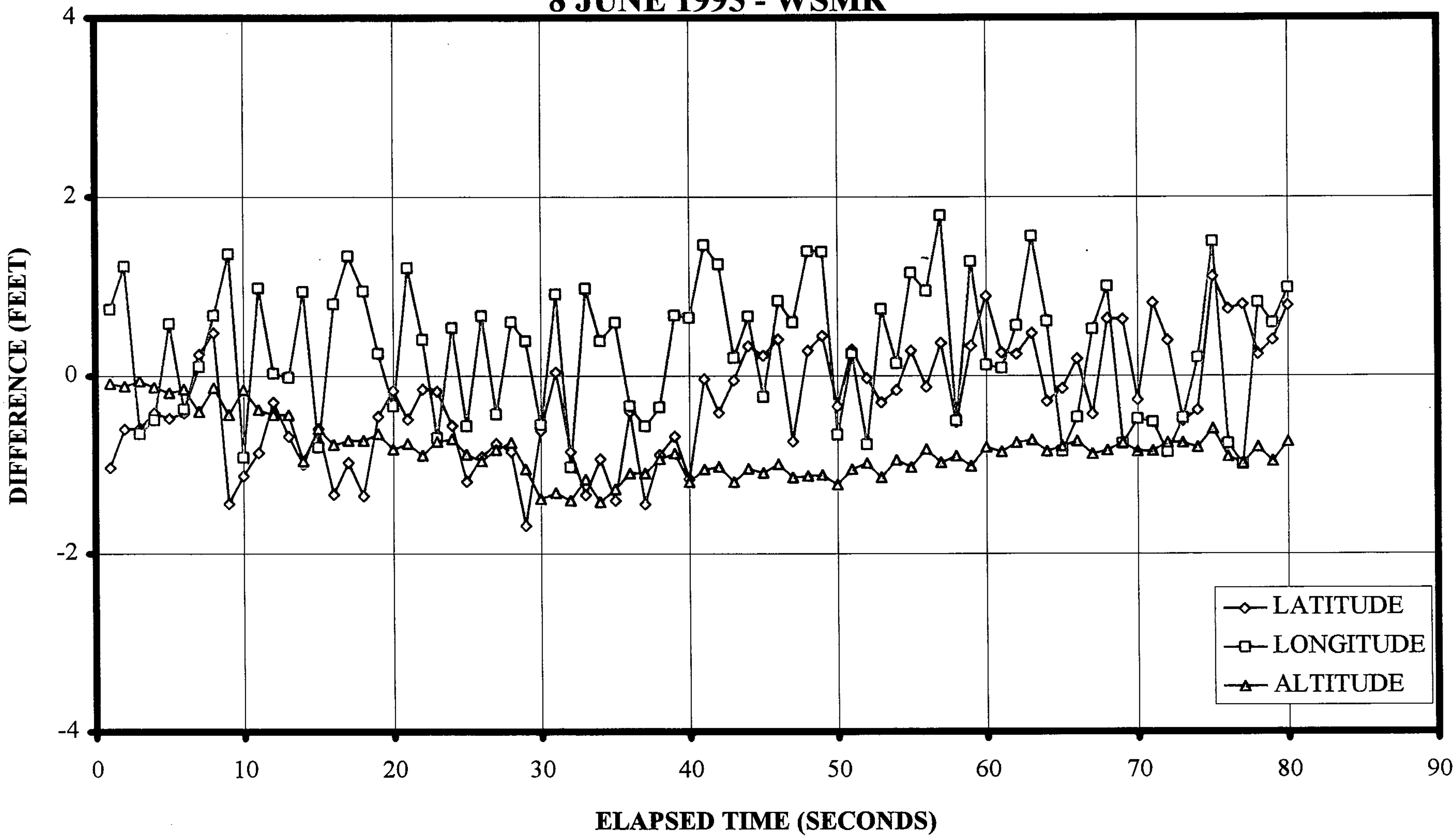



GPS vs OPTICS
PASS # 18 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
5
10
15
20
25
30
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

# GPS vs OPTICS
# PASS # 19 - 15 DEGREE BANK
# 8 JUNE 1995 - WSMR

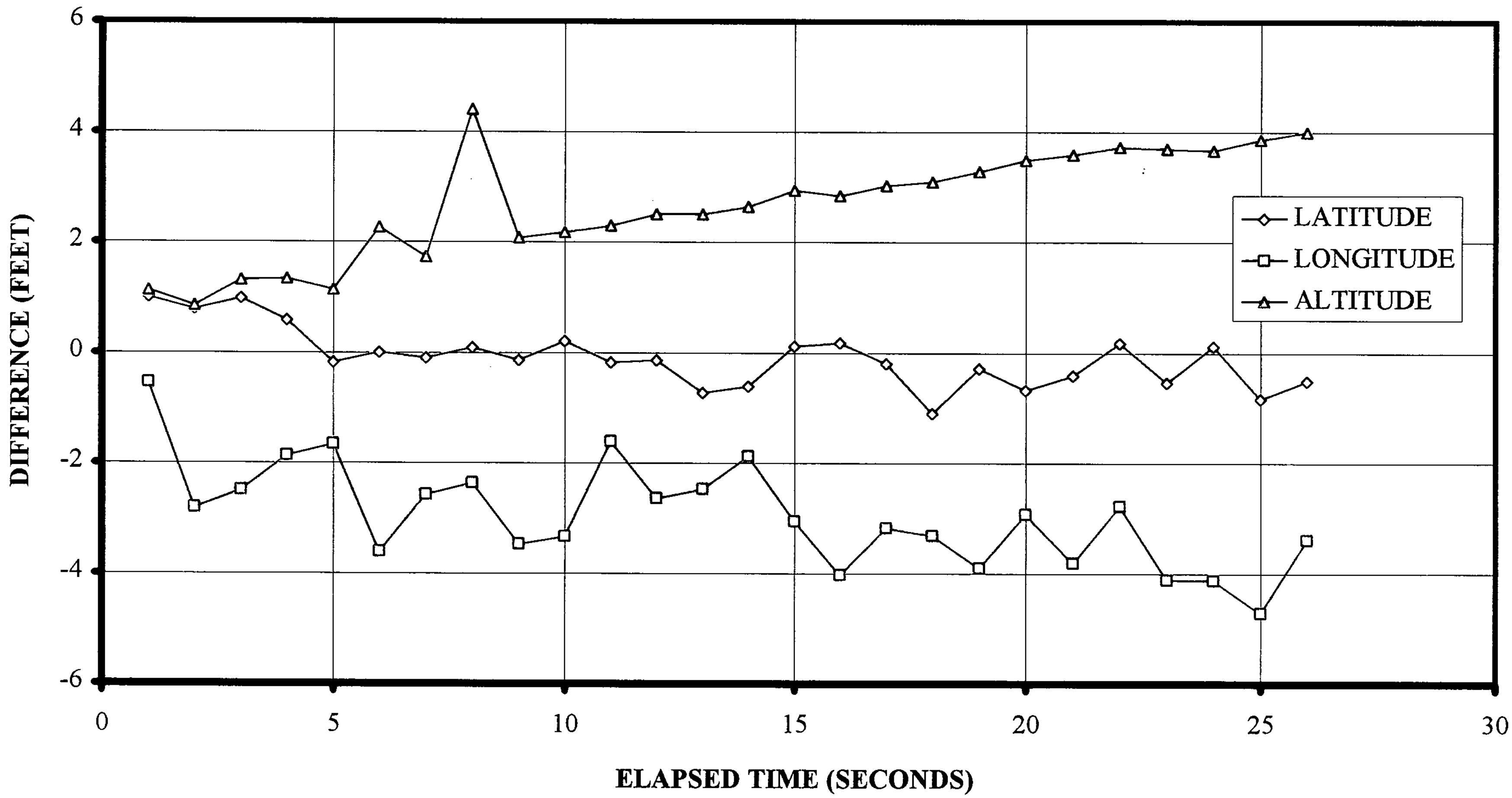


## GPS vs OPTICS
## PASS # 20 - 30 DEGREE BANK
## 8 JUNE 1995 - WSMR

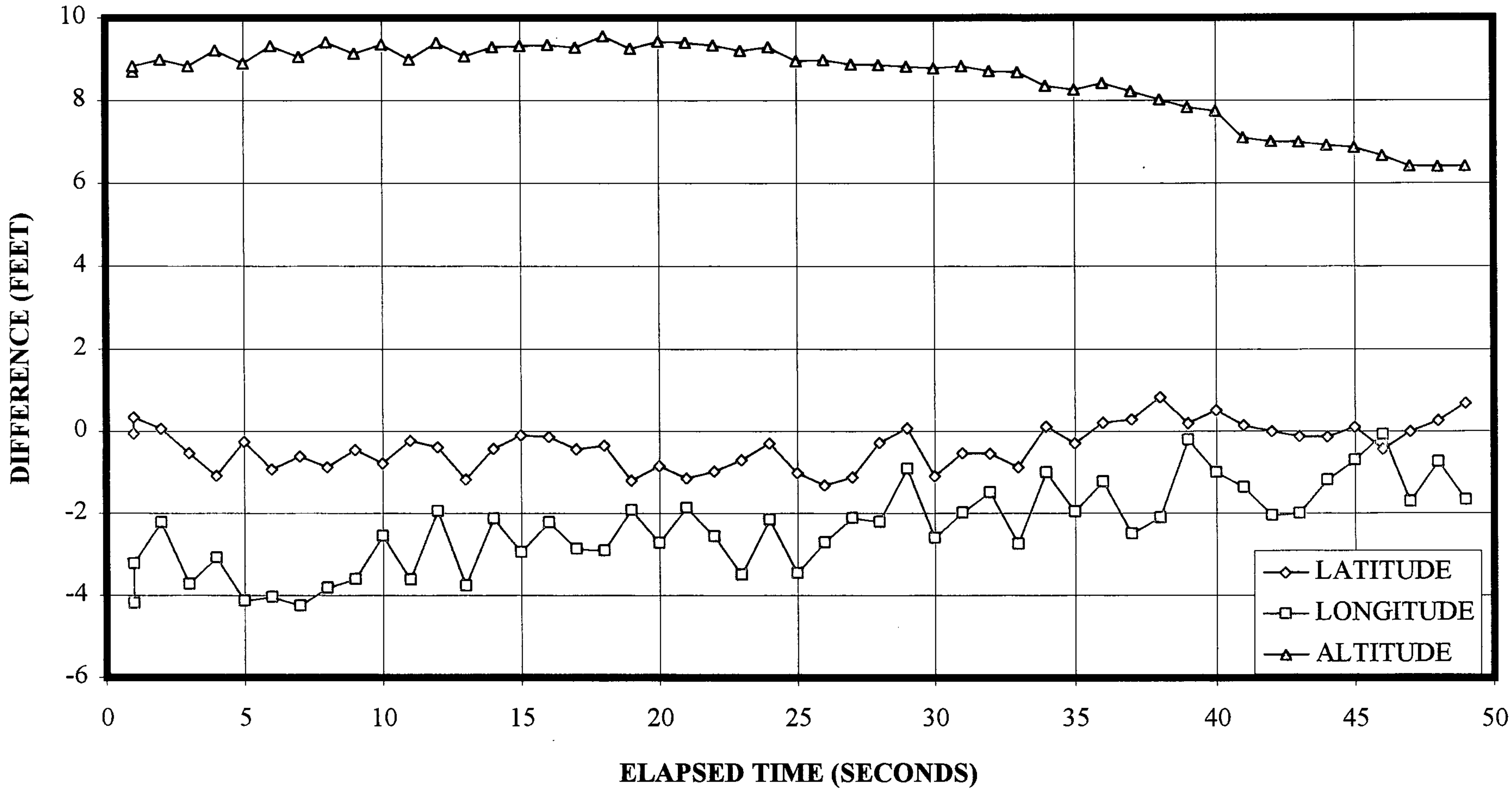


# APPENDIX D. COMPARISON OF REAL-TIME GPS POSITION SOLUTION TO WSMR OPTICS DATA

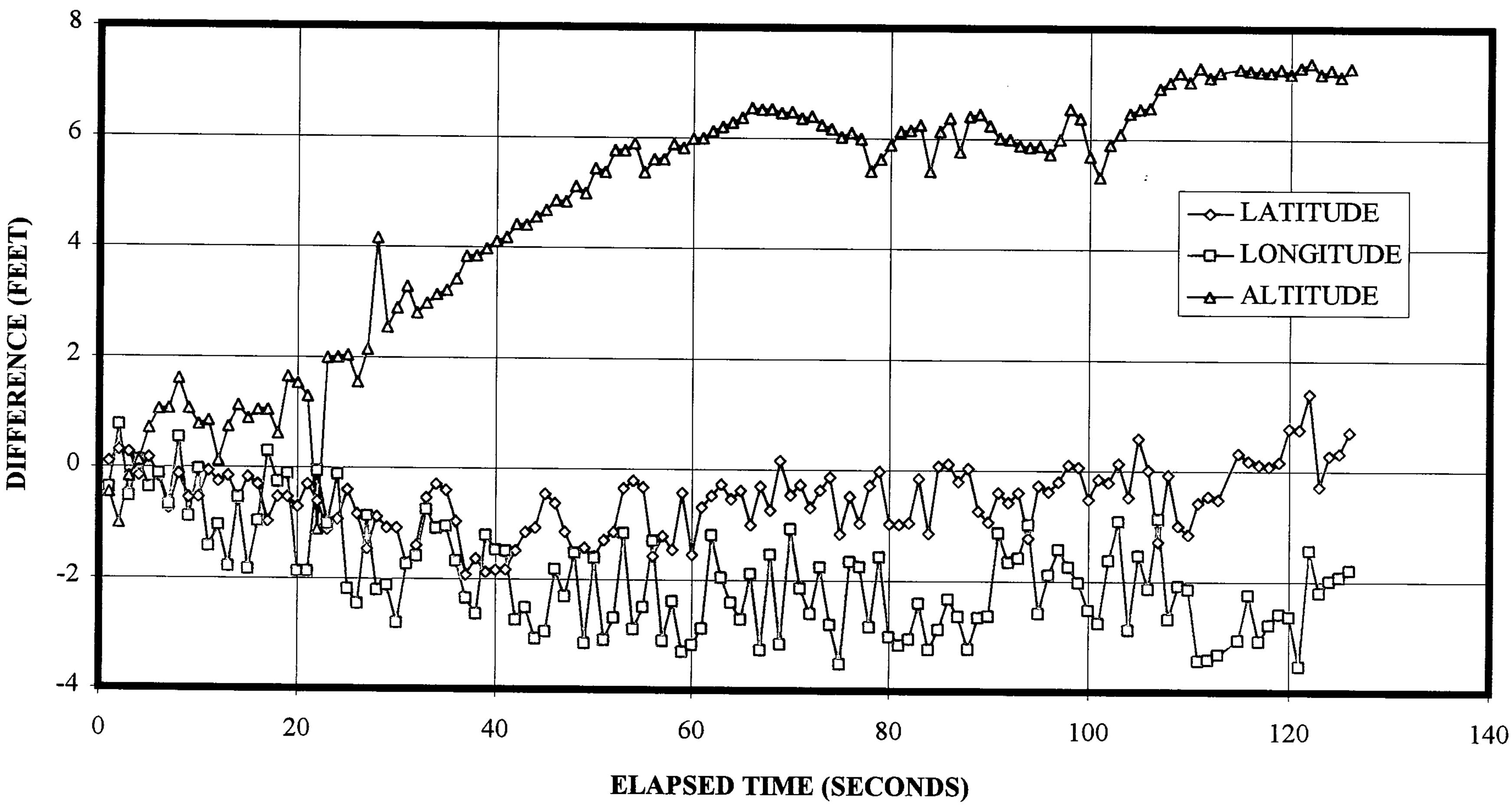
## REAL-TIME GPS vs OPTICS
## PASS # 1 - LEVEL FLIGHT
## 8 JUNE 1995 - WSMR



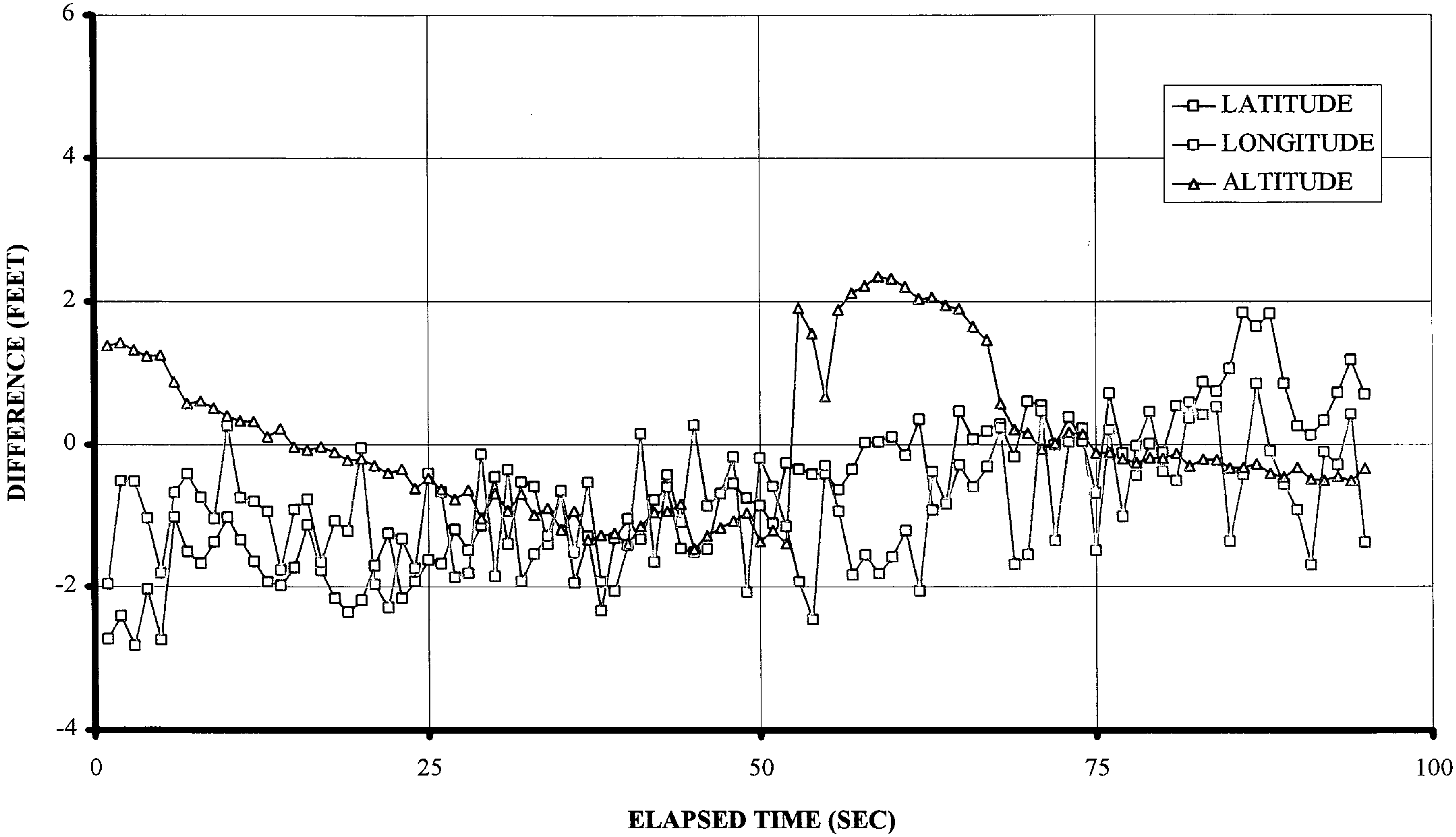
## REAL-TIME GPS vs OPTICS
## PASS # 2 - RAPID ALTITUDE CHANGES
## 8 JUNE 1995 - WSMR

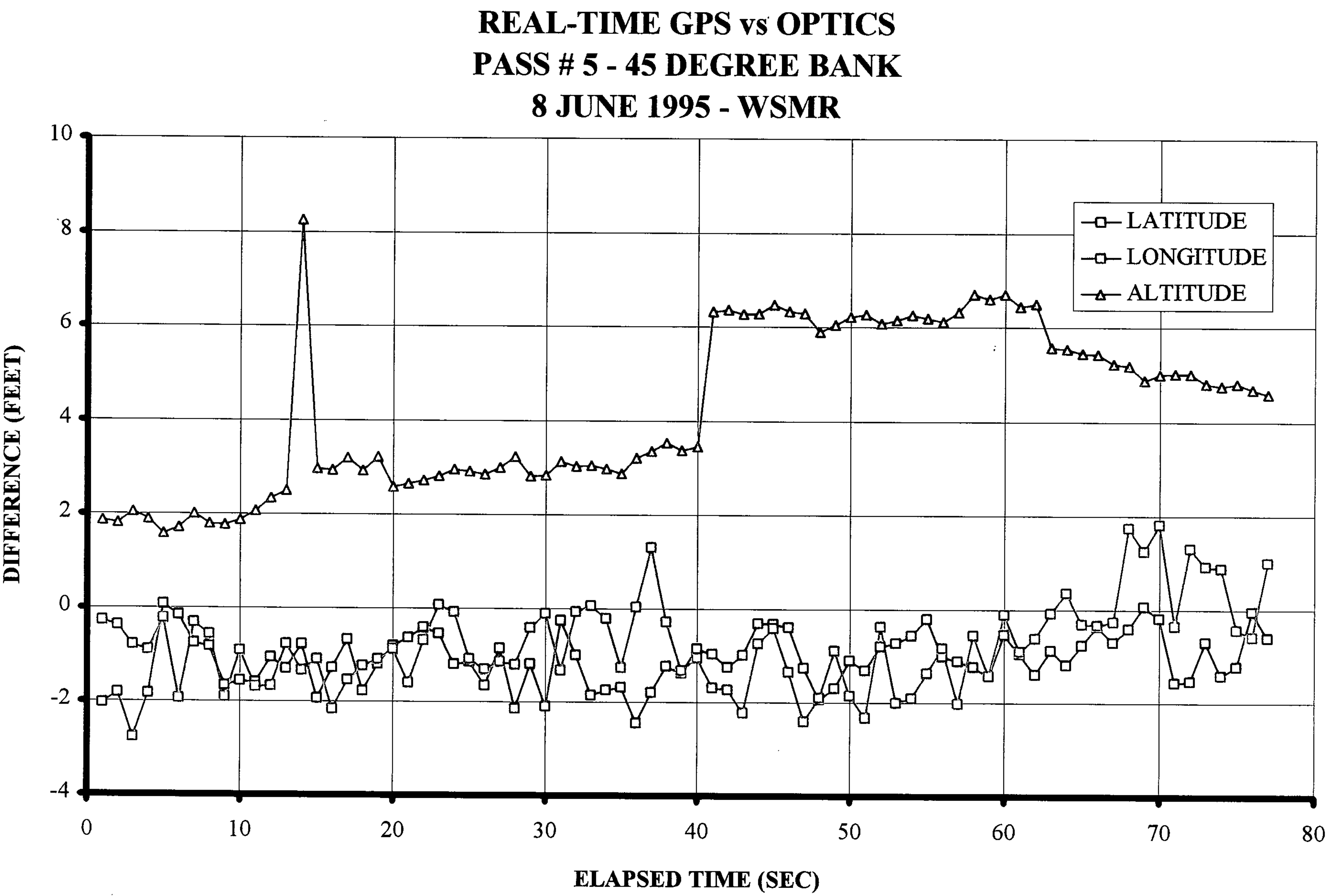


# REAL-TIME GPS vs OPTICS
# PASS # 3 - 15 DEGREE BANK
# 8 JUNE 1995 - WSMR

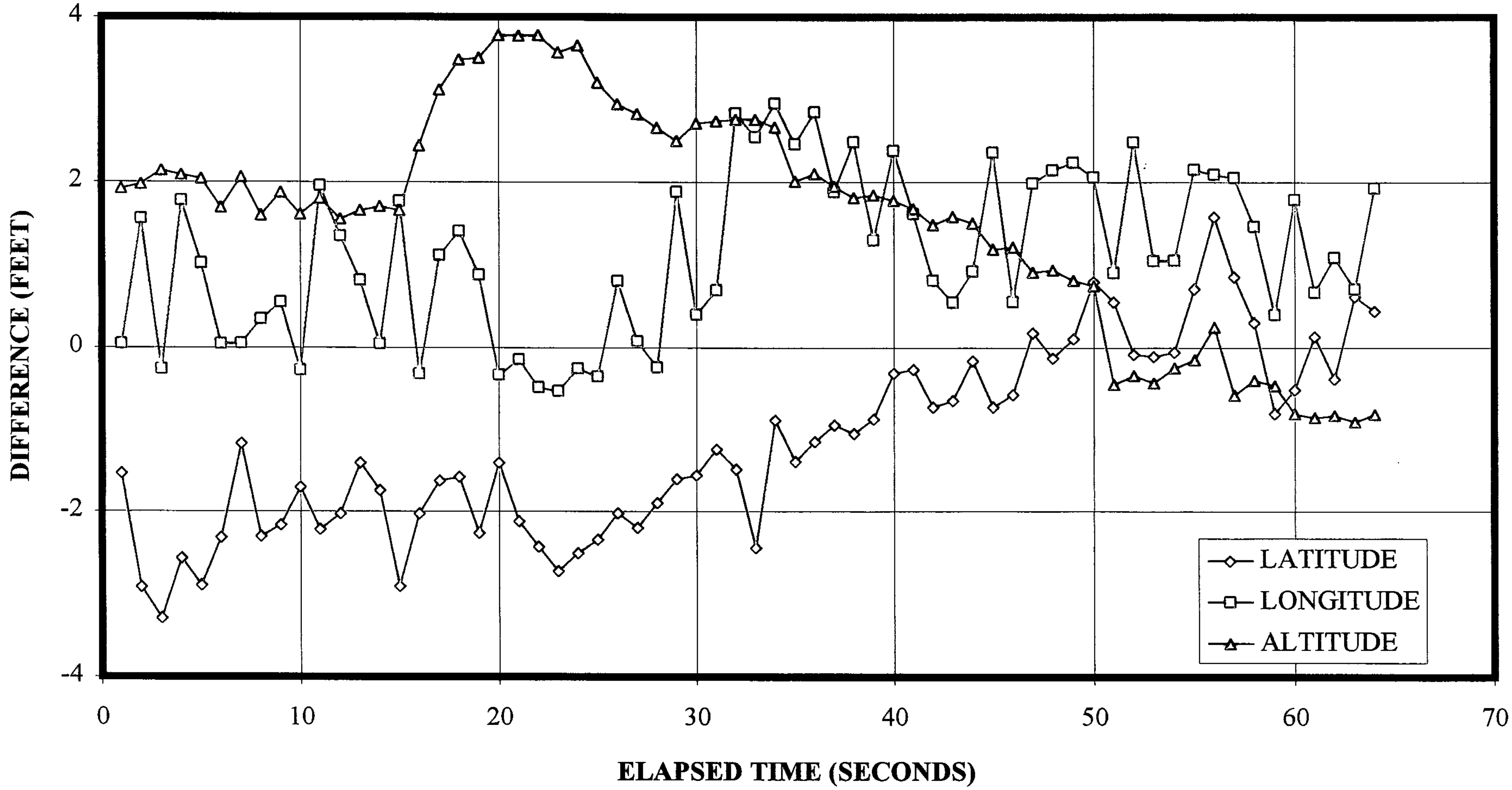


## REAL-TIME GPS vs OPTICS
## PASS # 4 - 30 DEGREE BANK
## 8 JUNE 1995 - WSMR

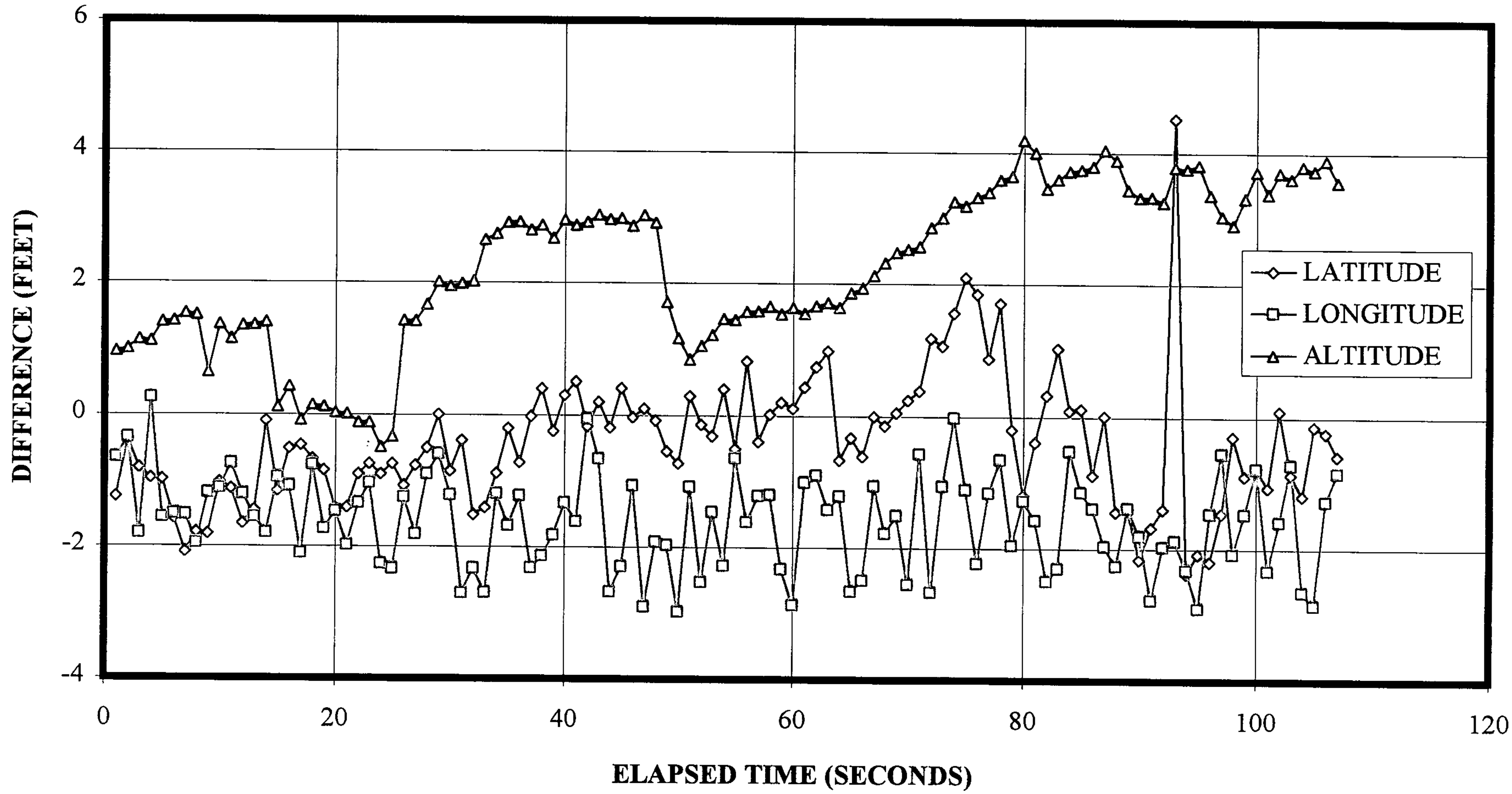



REAL-TIME GPS vs OPTICS
PASS # 5 - 45 DEGREE BANK
8 JUNE 1995 - WSMR
LATITUDE
LONGITUDE
ALTITUDE
DIFFERENCE (FEET)
ELAPSED TIME (SEC)
10
8
6
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80

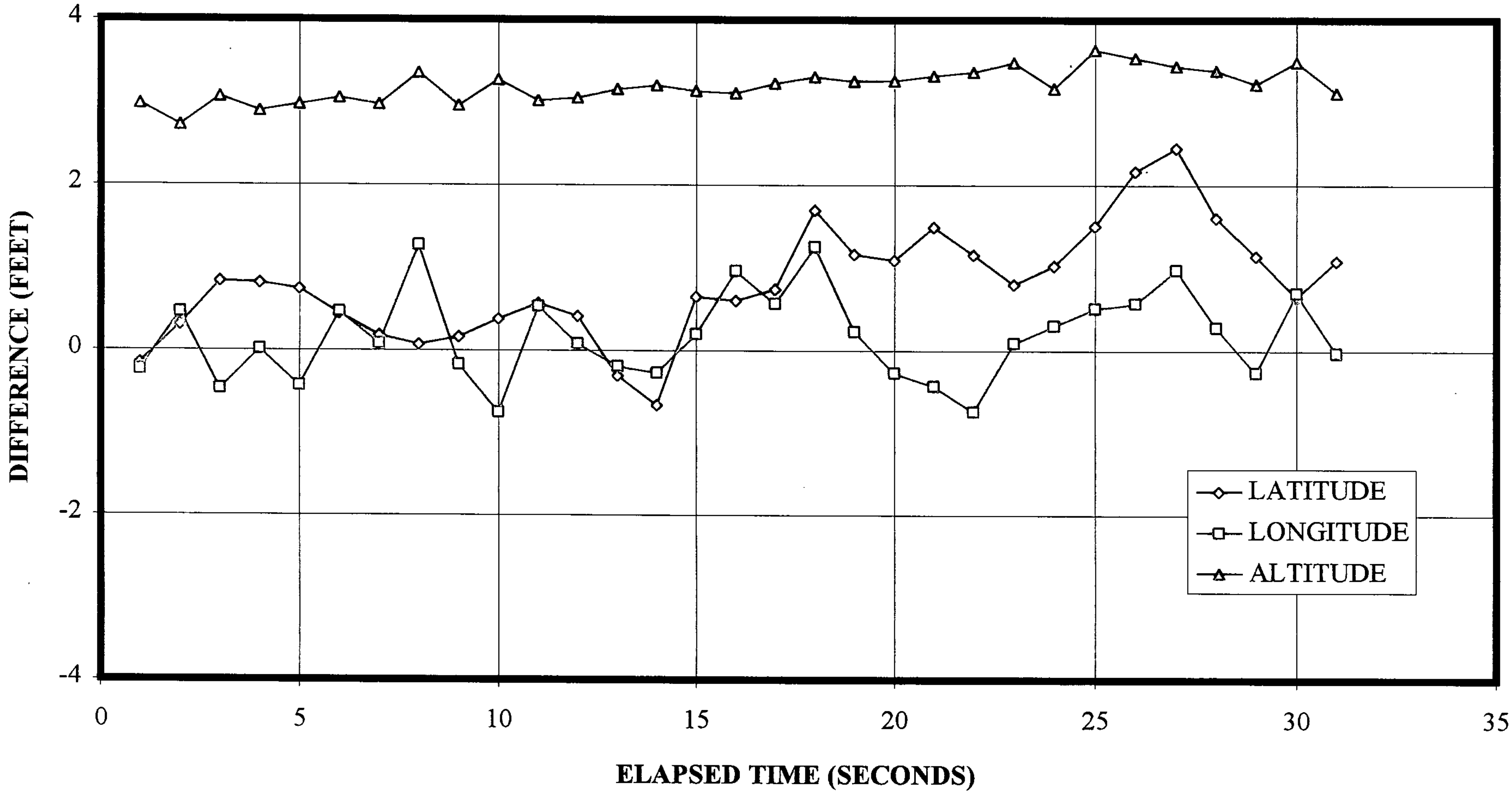
## REAL-TIME GPS vs OPTICS
## PASS # 6 - 60 DEGREE BANK
## 8 JUNE 1995 - WSMR



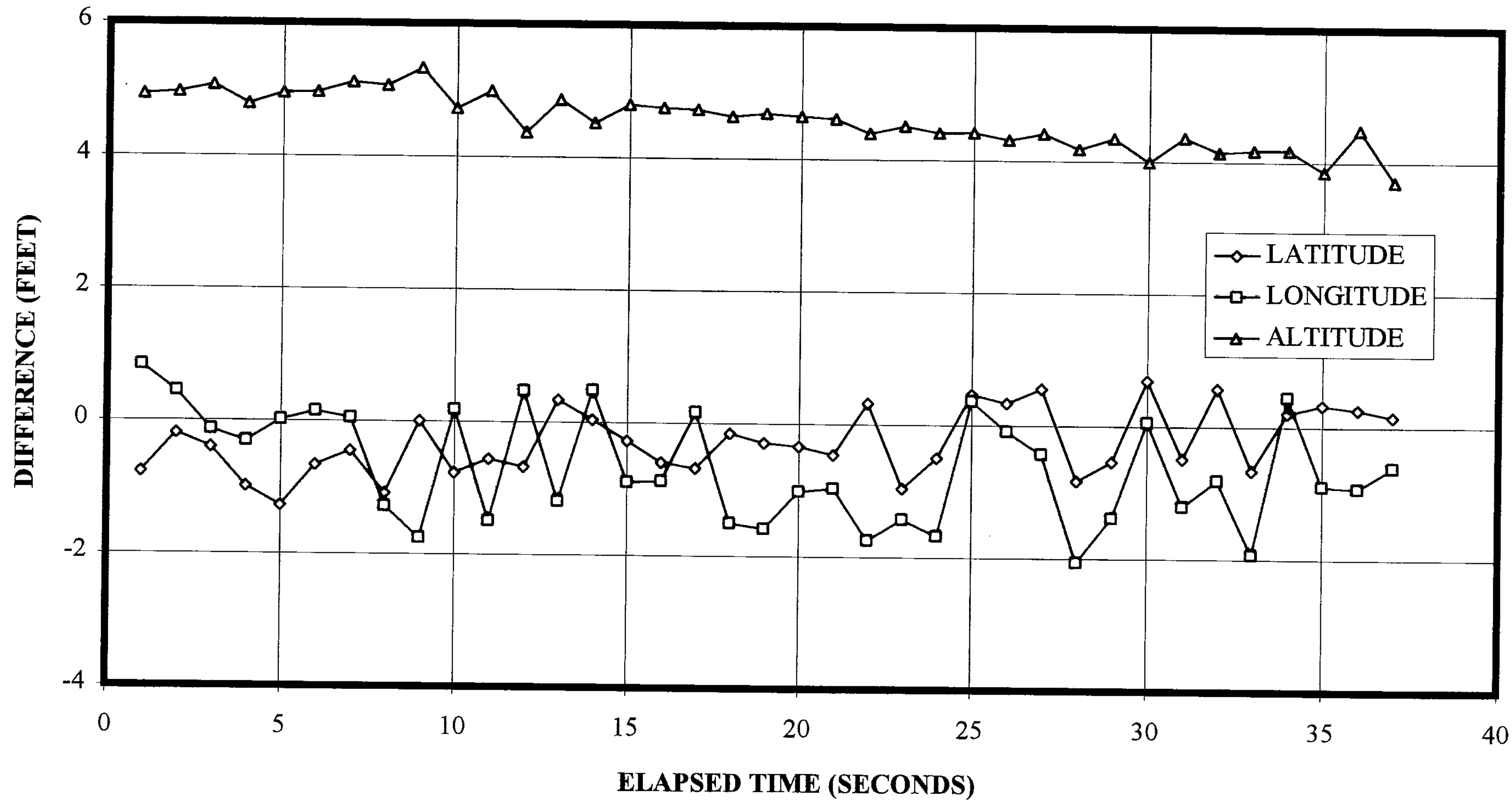
## REAL-TIME GPS vs OPTICS
## PASS # 7 - FIGURE EIGHT
## 8 JUNE 1995 - WSMR



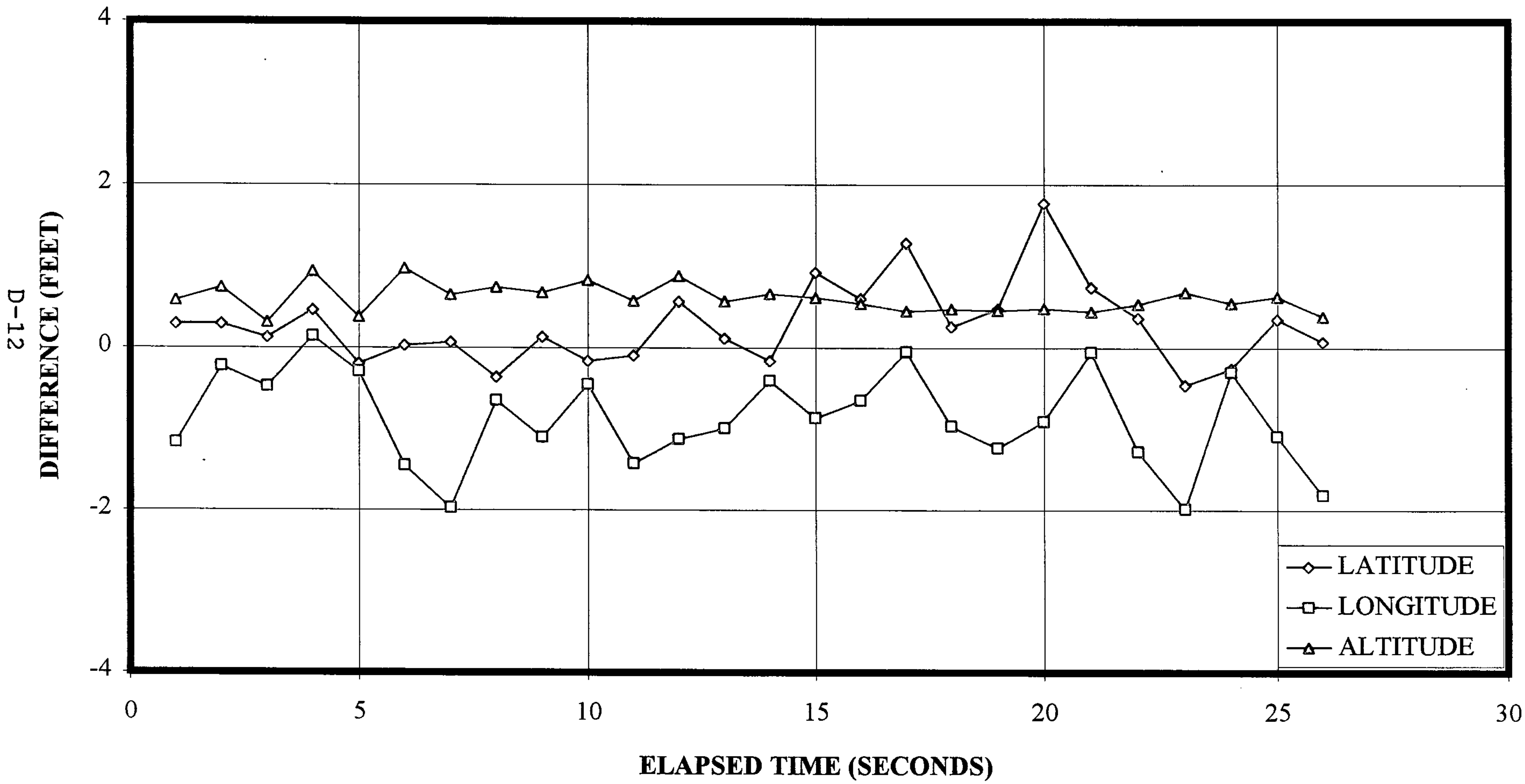
## REAL-TIME GPS vs OPTICS
## PASS # 8 - LEVEL FLIGHT
## 8 JUNE 1995 - WSMR



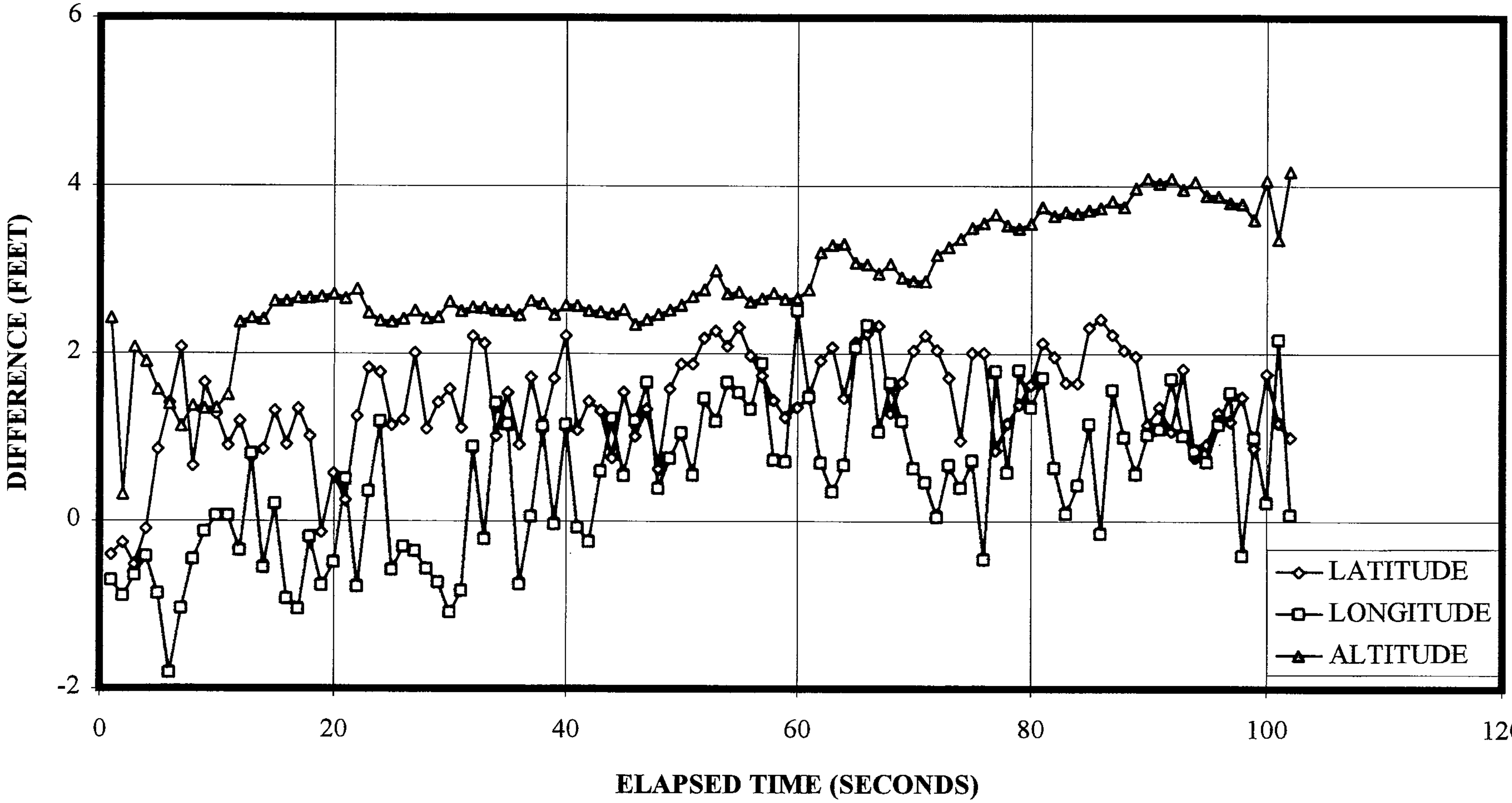
**REAL-TIME GPS vs OPTICS**
**PASS # 9 - RAPID ALTITUDE CHANGES**
**8 JUNE 1995 - WSMR**



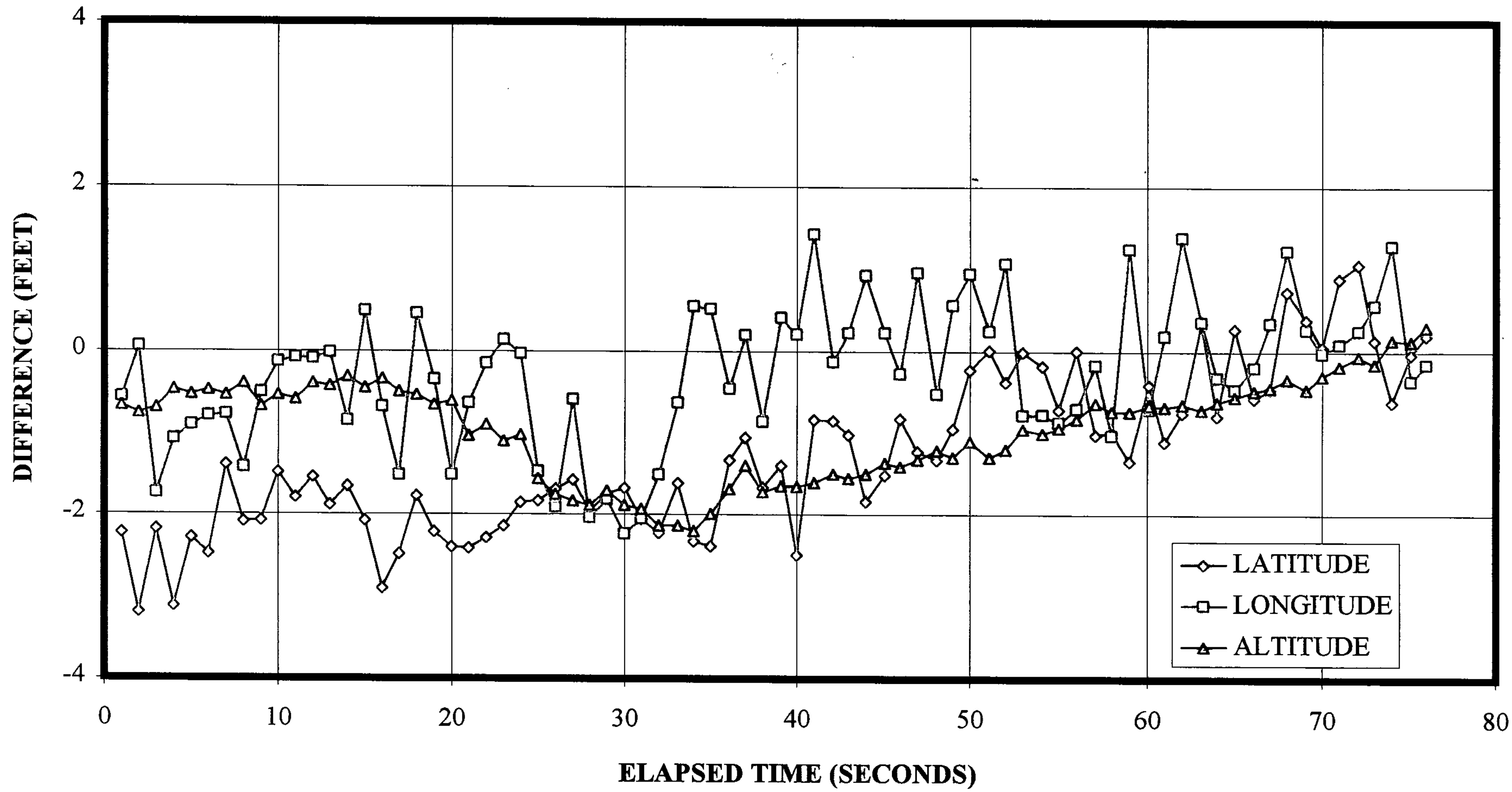
## REAL-TIME GPS vs OPTICS
## PASS # 10 - LEVEL FLIGHT
## 8 JUNE 1995 - WSMR



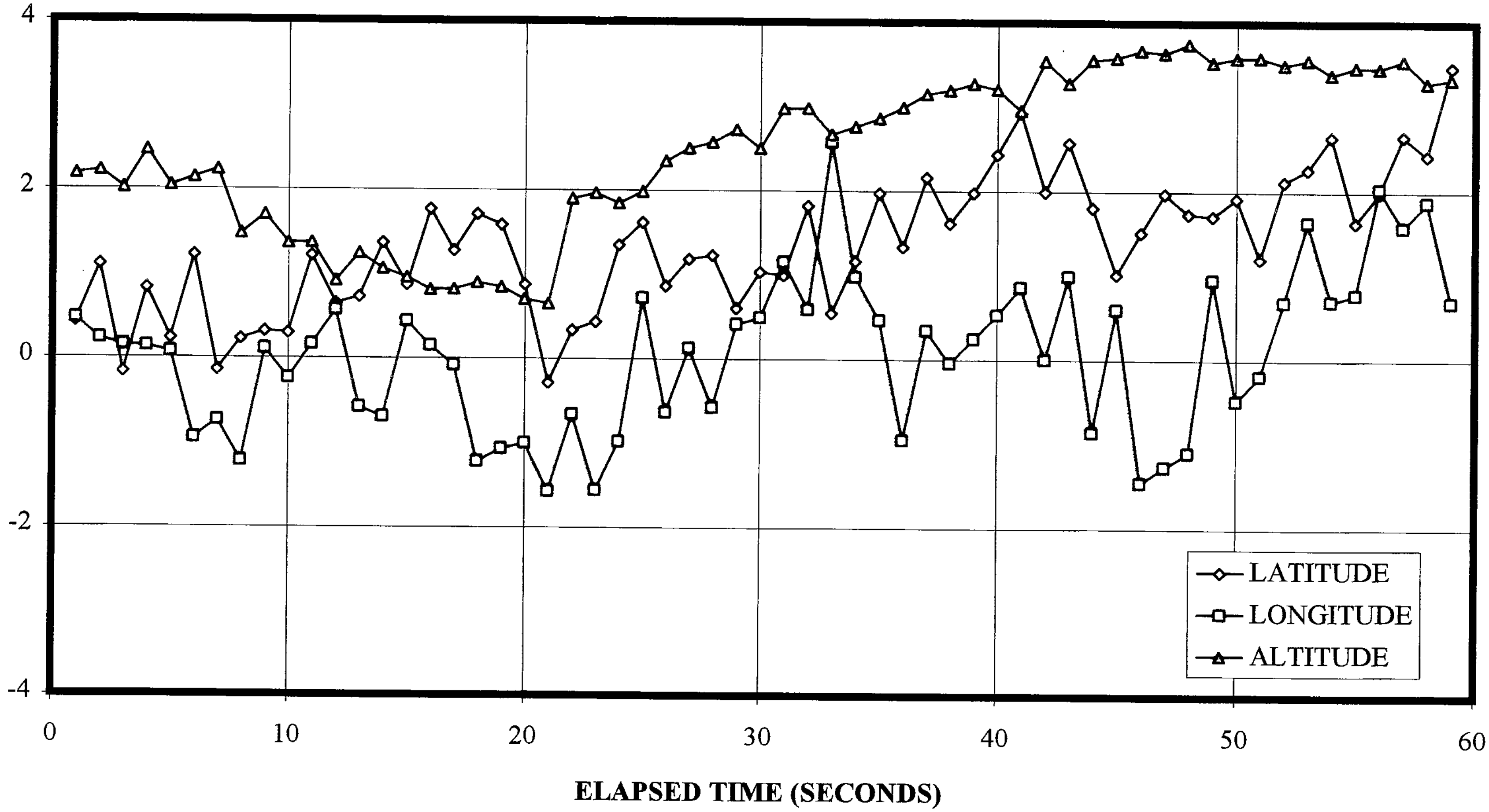
# REAL-TIME GPS vs OPTICS
# PASS # 11 - 15 DEGREE BANK
# 8 JUNE 1995 - WSMR



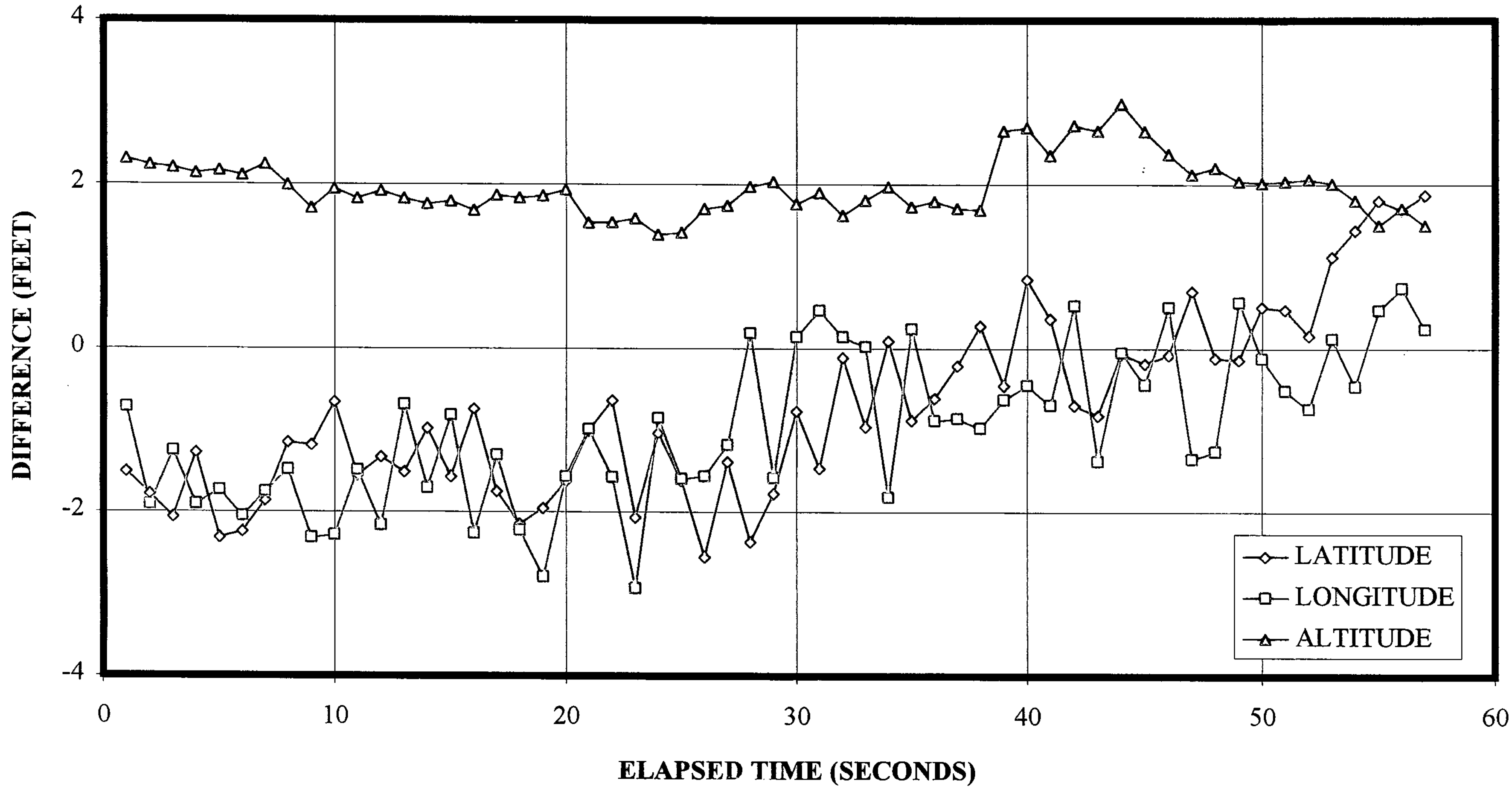
## REAL-TIME GPS vs OPTICS
## PASS # 12 - 30 DEGREE BANK
## 8 JUNE 1995 - WSMR



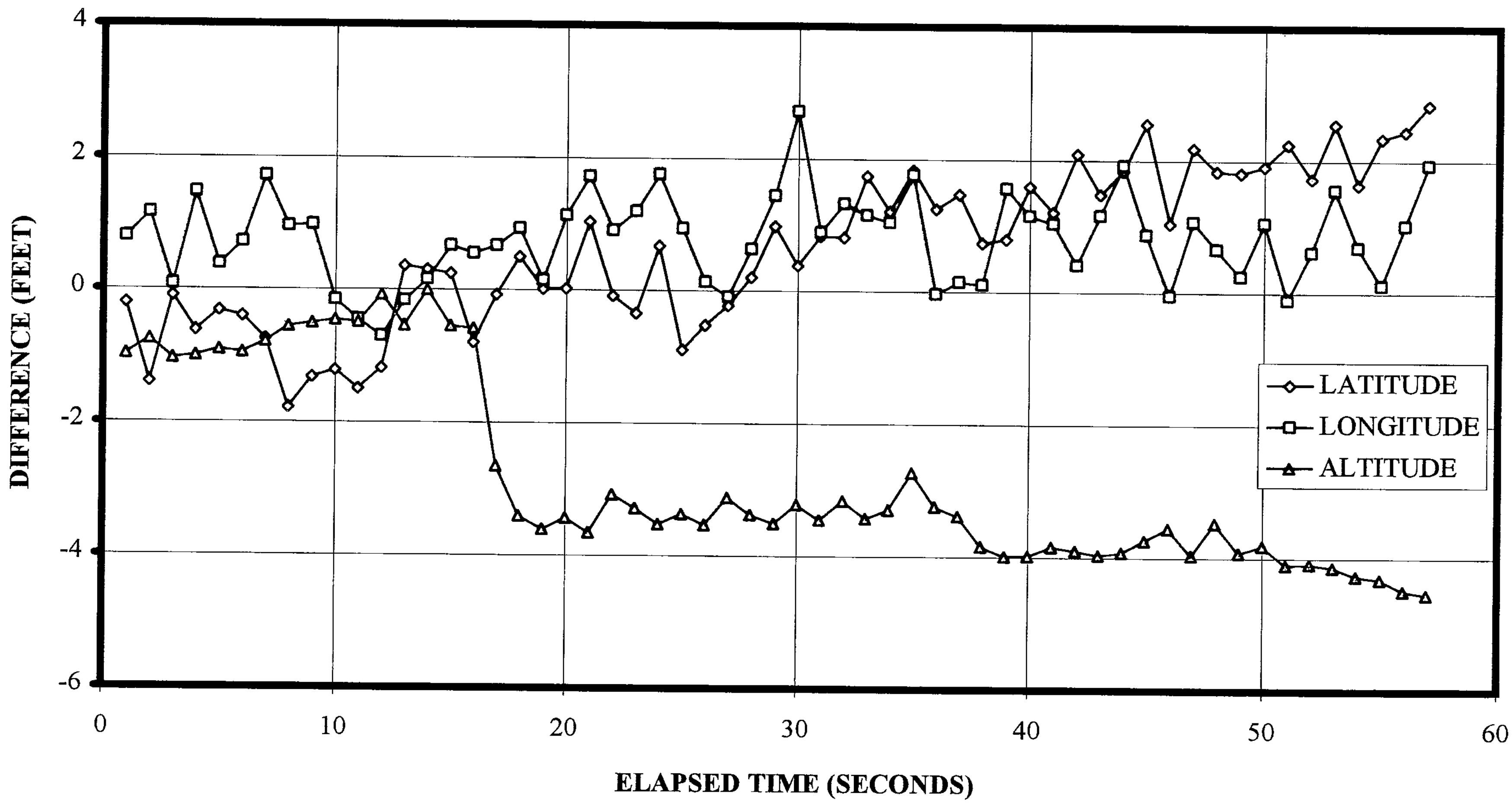
## REAL-TIME GPS vs OPTICS
## PASS # 13 - 45 DEGREE BANK
## 8 JUNE 1995 - WSMR



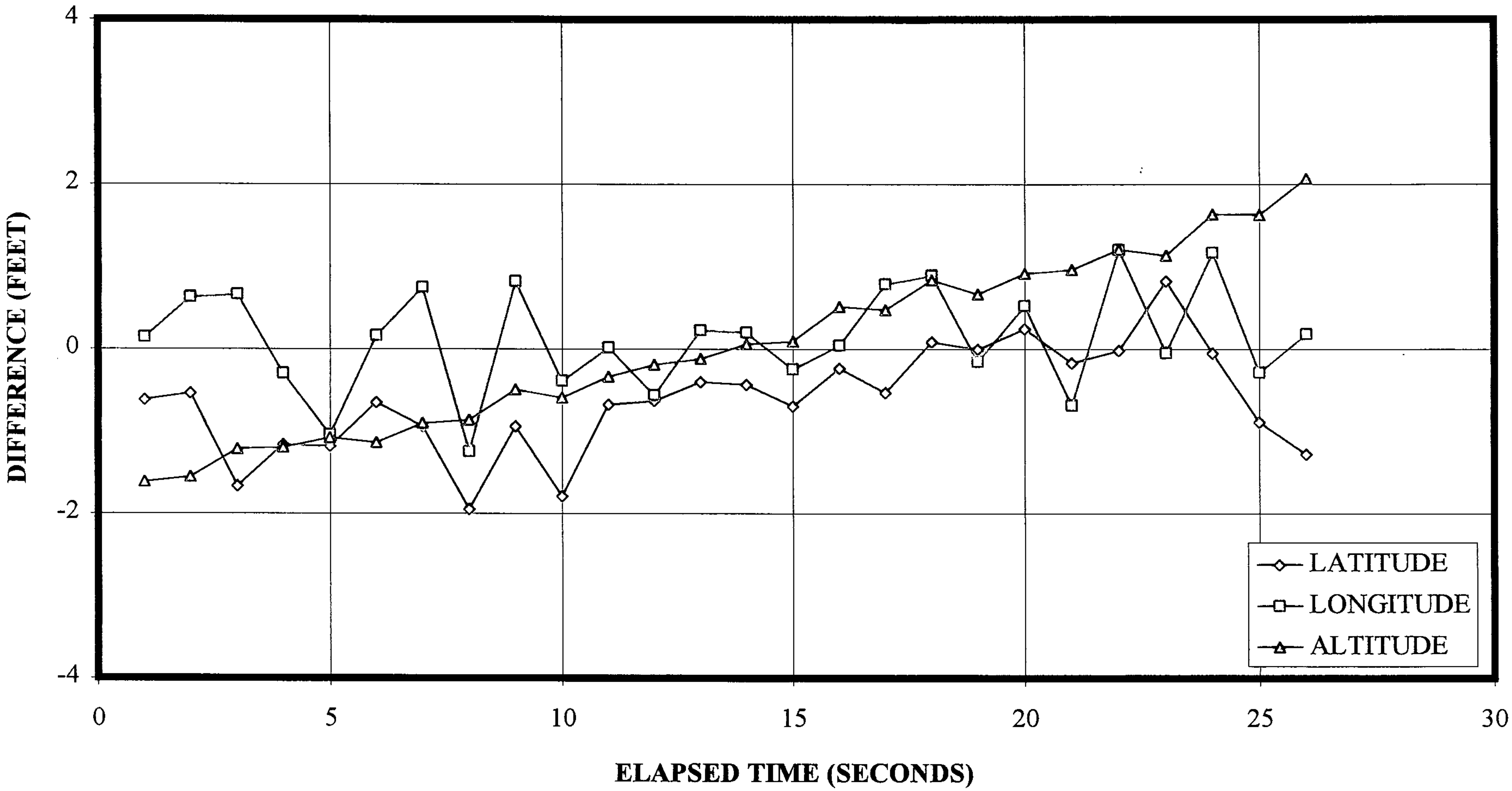
## REAL-TIME GPS vs OPTICS
## PASS # 14 - 60 DEGREE BANK
## 8 JUNE 1995 - WSMR



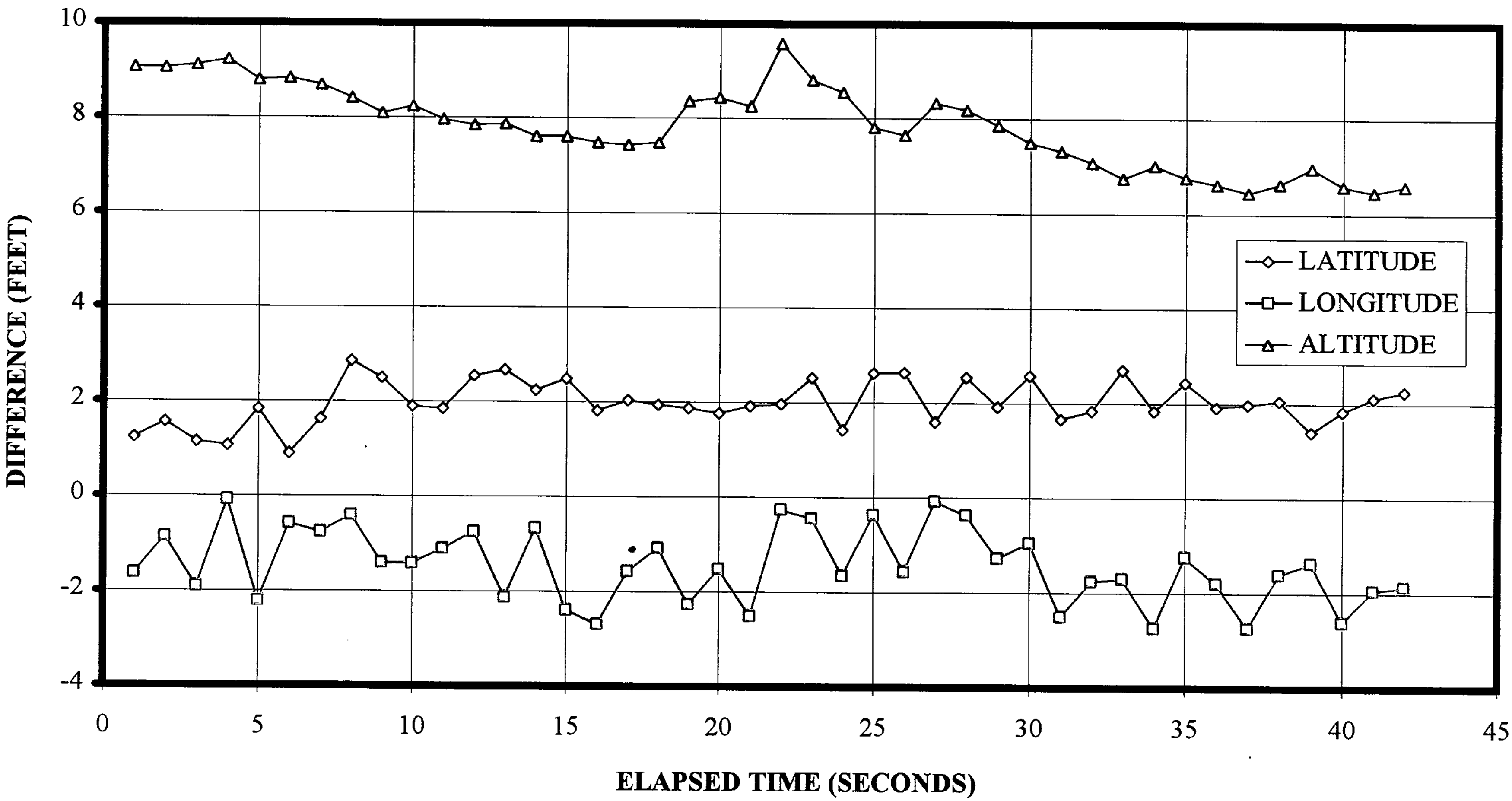
# REAL-TIME GPS vs OPTICS
# PASS # 15 - FIGURE EIGHT
# 8 JUNE 1995 - WSMR

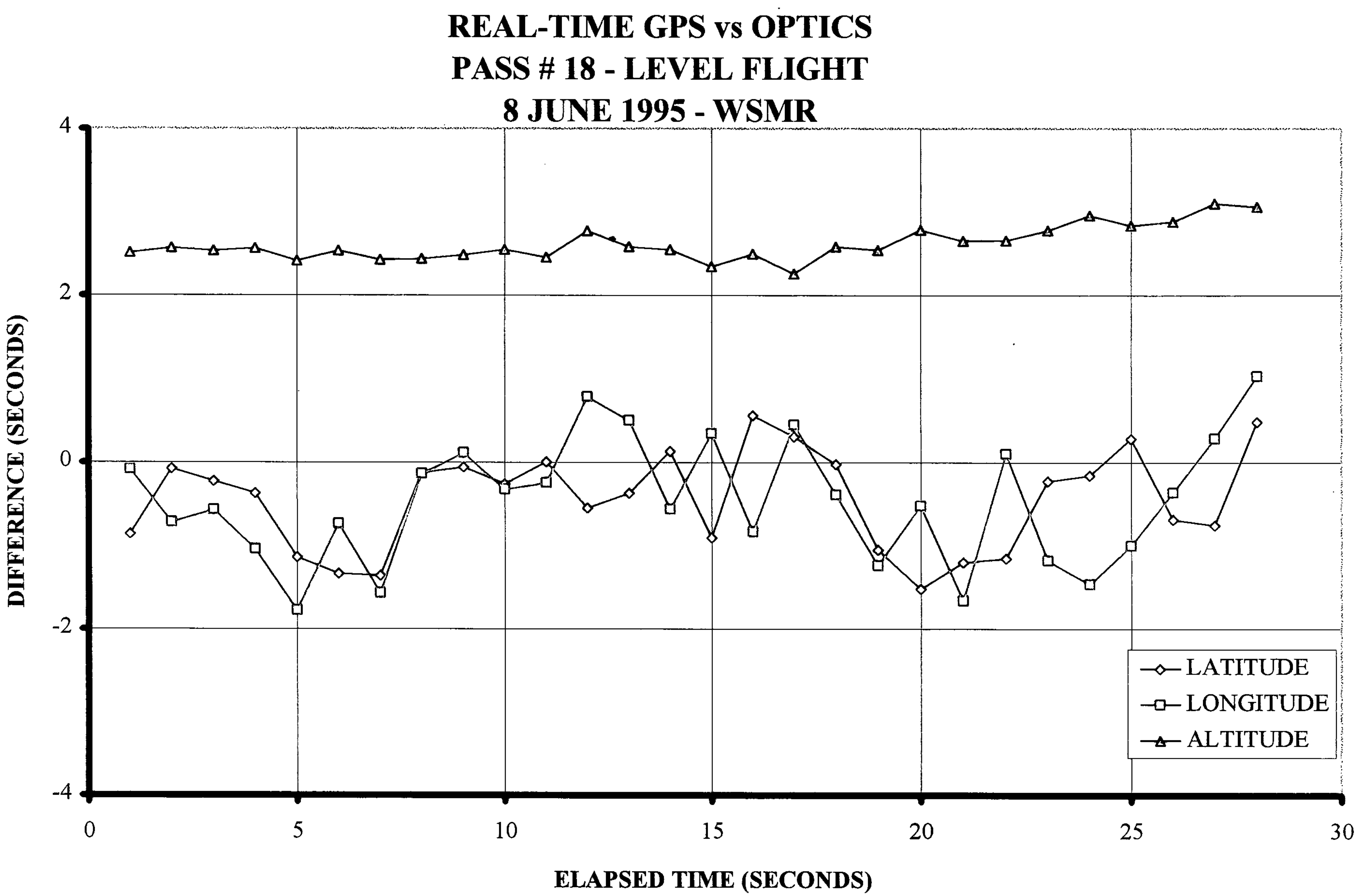


## REAL-TIME GPS vs OPTICS
## PASS # 16 - LEVEL FLIGHT
## 8 JUNE 1995 - WSMR

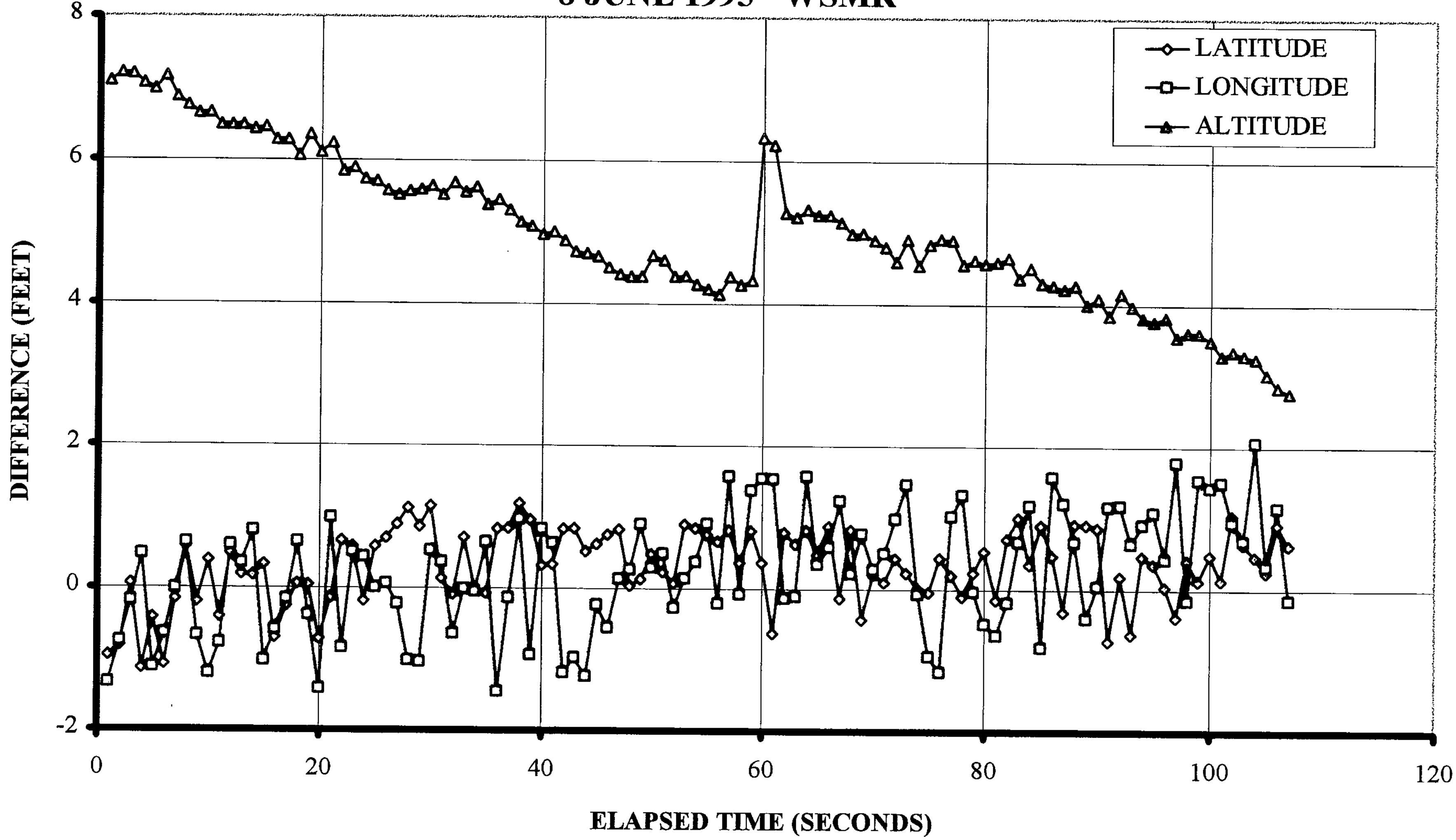


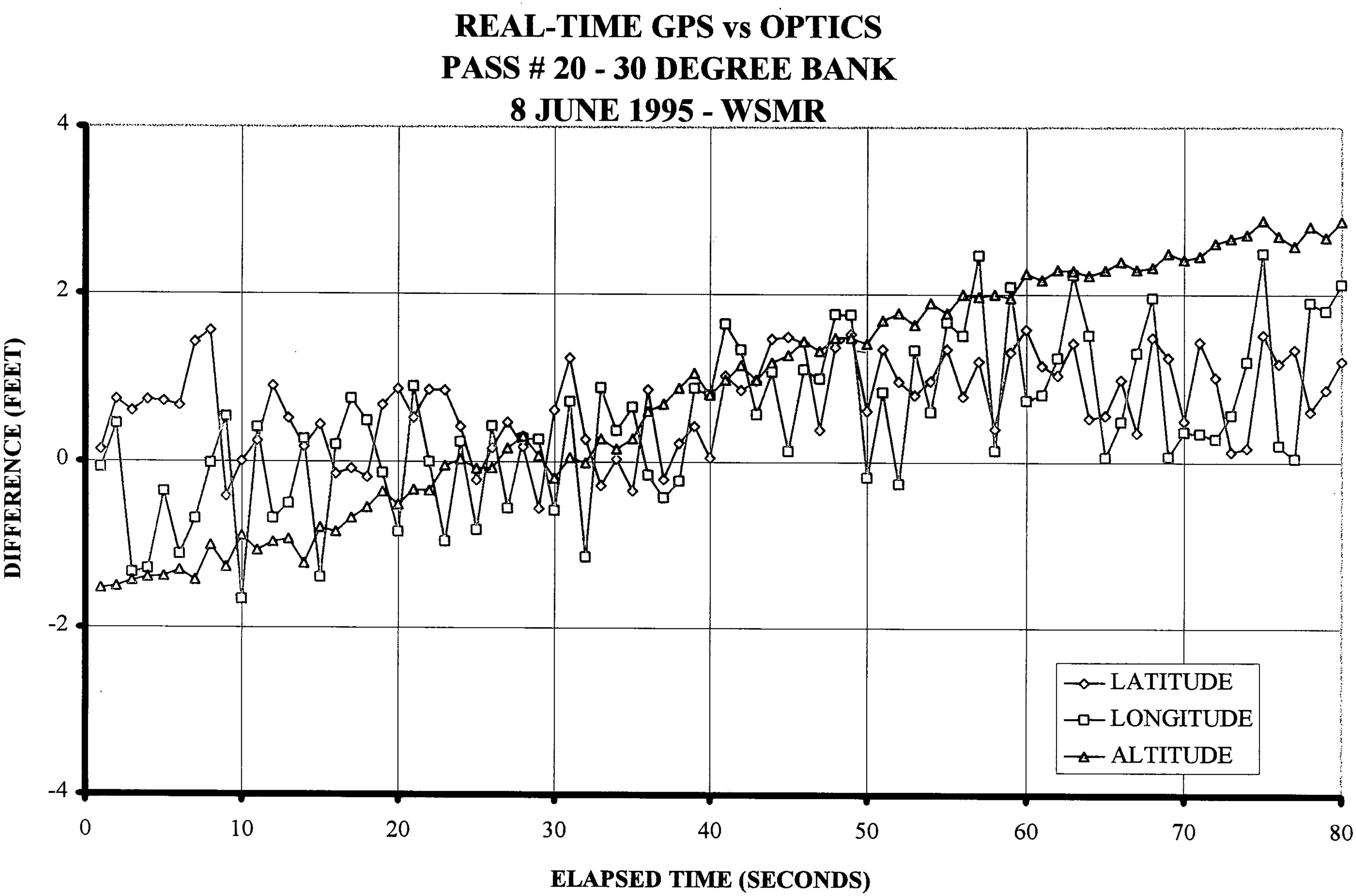
# REAL-TIME GPS vs OPTICS
# PASS # 17 - RAPID ALTITUDE CHANGES
# 8 JUNE 1995 - WSMR




REAL-TIME GPS vs OPTICS
PASS # 18 - LEVEL FLIGHT
8 JUNE 1995 - WSMR
DIFFERENCE (SECONDS)
4
2
0
-2
-4
0
5
10
15
20
25
30
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

REAL-TIME GPS vs OPTICS
PASS # 19 - 15 DEGREE BANK
8 JUNE 1995 - WSMR




REAL-TIME GPS vs OPTICS
PASS # 20 - 30 DEGREE BANK
8 JUNE 1995 - WSMR
DIFFERENCE (FEET)
4
2
0
-2
-4
0
10
20
30
40
50
60
70
80
ELAPSED TIME (SECONDS)
LATITUDE
LONGITUDE
ALTITUDE

# APPENDIX E. SUMMARY OF STATISTICS FOR POSTMISSION AND REAL-TIME PROCESSED DATA

## POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | AVERAGE LATITUDE DIFFERENCE (FEET) LAT | STD DEV LATITUDE DIFFERENCE (FEET) | MAXIMUM LATITUDE DIFFERENCE (FEET) | MINIMUM LATITUDE DIFFERENCE (FEET) |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | 0.675 | 0.432 | 1.426 | -0.364 |
| 66046.5 | 116.5 | 2 | 50 | 0.528 | 0.471 | 1.749 | -0.369 |
| 66257.4 | 327.4 | 3 | 125 | 0.160 | 0.587 | 2.057 | -1.163 |
| 66442.0 | 512.0 | 4 | 95 | -0.438 | 0.729 | 1.433 | -2.114 |
| 66601.0 | 671.0 | 5 | 77 | -0.380 | 0.865 | 1.572 | -2.763 |
| 66740.5 | 810.5 | 6 | 64 | 0.043 | 0.828 | 2.241 | -1.493 |
| 66906.0 | 976.0 | 7 | 107 | -0.430 | 1.004 | 4.454 | -2.603 |
| 67052.0 | 1122.0 | 8 | 31 | 0.716 | 0.695 | 2.404 | -0.805 |
| 67172.0 | 1242.0 | 9 | 37 | -0.723 | 0.475 | 0.201 | -1.510 |
| 67289.5 | 1359.5 | 10 | 26 | 0.285 | 0.514 | 1.897 | -0.480 |
| 67443.5 | 1513.5 | 11 | 102 | -0.330 | 0.763 | 1.353 | -2.377 |
| 67646.5 | 1716.5 | 12 | 76 | 0.286 | 0.630 | 1.705 | -1.155 |
| 67817.0 | 1887.0 | 13 | 59 | 0.146 | 0.999 | 2.667 | -1.848 |
| 67951.0 | 2021.0 | 14 | 57 | 0.023 | 1.095 | 2.529 | -1.848 |
| 68080.0 | 2150.0 | 15 | 57 | -0.217 | 1.015 | 1.976 | -2.179 |
| 68235.5 | 2305.5 | 16 | 26 | 1.224 | 0.608 | 2.486 | 0.002 |
| 68376.5 | 2446.5 | 17 | 42 | -1.388 | 0.441 | -0.506 | -2.427 |
| 68508.5 | 2578.5 | 18 | 28 | 0.904 | 0.686 | 2.165 | -0.361 |
| 68725.0 | 2795.0 | 19 | 107 | -0.567 | 0.612 | 0.811 | -2.183 |
| 68940.5 | 3010.5 | 20 | 80 | -0.281 | 0.654 | 1.121 | -1.683 |

## POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | AVERAGE LONGITUDE DIFFERENCE (FEET) LONG | STD DEV LONGITUDE DIFFERENCE (FEET) | MAXIMUM LONGITUDE DIFFERENCE (FEET) | MINIMUM LONGITUDE DIFFERENCE (FEET) |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | 0.434 | 0.782 | 2.387 | -0.859 |
| 66046.5 | 116.5 | 2 | 50 | -0.903 | 0.674 | 0.469 | -1.949 |
| 66257.4 | 327.4 | 3 | 125 | -0.549 | 0.725 | 1.035 | -2.097 |
| 66442.0 | 512.0 | 4 | 95 | -0.382 | 0.905 | 1.542 | -2.291 |
| 66601.0 | 671.0 | 5 | 77 | -0.140 | 0.796 | 1.992 | -1.537 |
| 66740.5 | 810.5 | 6 | 64 | -0.262 | 0.909 | 1.703 | -1.616 |
| 66906.0 | 976.0 | 7 | 107 | -0.317 | 0.754 | 1.517 | -1.831 |
| 67052.0 | 1122.0 | 8 | 31 | -0.522 | 0.521 | 0.733 | -1.387 |
| 67172.0 | 1242.0 | 9 | 37 | -0.404 | 0.790 | 0.784 | -1.834 |
| 67289.5 | 1359.5 | 10 | 26 | 0.237 | 0.650 | 1.344 | -1.027 |
| 67443.5 | 1513.5 | 11 | 102 | -0.550 | 0.718 | 1.144 | -2.054 |
| 67646.5 | 1716.5 | 12 | 76 | -0.237 | 0.793 | 1.612 | -1.850 |
| 67817.0 | 1887.0 | 13 | 59 | 0.012 | 0.957 | 2.547 | -1.523 |
| 67951.0 | 2021.0 | 14 | 57 | -0.296 | 0.817 | 1.265 | -2.028 |
| 68080.0 | 2150.0 | 15 | 57 | -0.223 | 0.798 | 1.924 | -2.203 |
| 68235.5 | 2305.5 | 16 | 26 | 0.511 | 0.649 | 1.603 | -0.959 |
| 68376.5 | 2446.5 | 17 | 42 | 0.137 | 0.727 | 1.272 | -1.107 |
| 68508.5 | 2578.5 | 18 | 28 | 0.757 | 0.768 | 2.303 | -0.545 |
| 68725.0 | 2795.0 | 19 | 107 | 0.332 | 0.762 | 2.004 | -1.344 |
| 68940.5 | 3010.5 | 20 | 80 | 0.301 | 0.761 | 1.791 | -1.031 |

## POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | AVERAGE ALTITUDE DIFFERENCE (FEET) ALT | STD DEV ALTITUDE DIFFERENCE (FEET) | MAXIMUM ALTITUDE DIFFERENCE (FEET) | MINIMUM ALTITUDE DIFFERENCE (FEET) |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | -0.160 | 0.116 | 0.123 | -0.333 |
| 66046.5 | 116.5 | 2 | 50 | 2.345 | 0.485 | 3.122 | 1.353 |
| 66257.4 | 327.4 | 3 | 125 | 1.996 | 0.482 | 3.460 | 1.424 |
| 66442.0 | 512.0 | 4 | 95 | 1.793 | 0.351 | 2.439 | 1.033 |
| 66601.0 | 671.0 | 5 | 77 | 0.361 | 0.459 | 1.665 | -0.287 |
| 66740.5 | 810.5 | 6 | 64 | 0.800 | 0.411 | 1.669 | 0.031 |
| 66906.0 | 976.0 | 7 | 107 | 0.336 | 0.337 | 1.150 | -0.427 |
| 67052.0 | 1122.0 | 8 | 31 | 0.971 | 0.299 | 1.500 | 0.357 |
| 67172.0 | 1242.0 | 9 | 37 | 0.708 | 0.356 | 1.370 | -0.110 |
| 67289.5 | 1359.5 | 10 | 26 | 1.014 | 0.315 | 1.630 | 0.373 |
| 67443.5 | 1513.5 | 11 | 102 | -0.137 | 0.326 | 0.721 | -0.711 |
| 67646.5 | 1716.5 | 12 | 76 | 0.758 | 0.206 | 1.283 | 0.247 |
| 67817.0 | 1887.0 | 13 | 59 | 0.036 | 0.362 | 0.670 | -0.830 |
| 67951.0 | 2021.0 | 14 | 57 | 0.606 | 0.413 | 1.380 | -0.240 |
| 68080.0 | 2150.0 | 15 | 57 | 0.885 | 0.393 | 1.607 | 0.107 |
| 68235.5 | 2305.5 | 16 | 26 | 0.295 | 0.100 | 0.493 | 0.137 |
| 68376.5 | 2446.5 | 17 | 42 | -1.395 | 0.209 | -0.973 | -1.747 |
| 68508.5 | 2578.5 | 18 | 28 | 0.393 | 0.225 | 0.793 | 0.057 |
| 68725.0 | 2795.0 | 19 | 107 | -1.274 | 0.379 | -0.439 | -1.940 |
| 68940.5 | 3010.5 | 20 | 80 | -0.827 | 0.320 | -0.059 | -1.425 |

# POSTMISSION GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | | LINEAR ERROR PROBABLE (VERTICAL) | CIRCULAR ERROR PROBABLE (HORIZONTAL) | SPHERICAL ERROR PROBABLE |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | | 0.078039732 | 0.714985639 | 0.681347702 |
| 66046.5 | 116.5 | 2 | 50 | | 0.327187579 | 0.67410201 | 0.835131309 |
| 66257.4 | 327.4 | 3 | 125 | | 0.325029377 | 0.772653027 | 0.91923046 |
| 66442.0 | 512.0 | 4 | 95 | | 0.236835291 | 0.961630183 | 1.01661308 |
| 66601.0 | 671.0 | 5 | 77 | | 0.309699137 | 0.97762084 | 1.085901475 |
| 66740.5 | 810.5 | 6 | 64 | | 0.277274789 | 1.022500308 | 1.100304108 |
| 66906.0 | 976.0 | 7 | 107 | | 0.227095599 | 1.034909478 | 1.072963901 |
| 67052.0 | 1122.0 | 8 | 31 | | 0.201801787 | 0.715785187 | 0.77610247 |
| 67172.0 | 1242.0 | 9 | 37 | | 0.240425908 | 0.744766339 | 0.830670404 |
| 67289.5 | 1359.5 | 10 | 26 | | 0.212432111 | 0.685129904 | 0.757511421 |
| 67443.5 | 1513.5 | 11 | 102 | | 0.220204808 | 0.87194796 | 0.925950379 |
| 67646.5 | 1716.5 | 12 | 76 | | 0.139142448 | 0.837573963 | 0.834437608 |
| 67817.0 | 1887.0 | 13 | 59 | | 0.244114083 | 1.151812645 | 1.187603704 |
| 67951.0 | 2021.0 | 14 | 57 | | 0.278667275 | 1.12560681 | 1.191065053 |
| 68080.0 | 2150.0 | 15 | 57 | | 0.264780526 | 1.067357646 | 1.129834352 |
| 68235.5 | 2305.5 | 16 | 26 | | 0.067207662 | 0.73991608 | 0.694804813 |
| 68376.5 | 2446.5 | 17 | 42 | | 0.141082541 | 0.687586259 | 0.705422777 |
| 68508.5 | 2578.5 | 18 | 28 | | 0.151887466 | 0.855983394 | 0.860140027 |
| 68725.0 | 2795.0 | 19 | 107 | | 0.255918343 | 0.8087349 | 0.898097304 |
| 68940.5 | 3010.5 | 20 | 80 | | 0.215897159 | 0.83303505 | 0.888822335 |
| | | | | | | | |
| | | | | MEANS: | 0.220736181 | 0.864181881 | 0.919597734 |

## REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | AVERAGE LATITUDE DIFFERENCE (FEET) LAT | STD DEV LATITUDE DIFFERENCE (FEET) | MAXIMUM LATITUDE DIFFERENCE (FEET) | MINIMUM LATITUDE DIFFERENCE (FEET) |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | -0.079 | 0.531 | 1.008 | -1.091 |
| 66046.5 | 116.5 | 2 | 50 | -0.351 | 0.531 | 0.839 | -1.315 |
| 66257.4 | 327.4 | 3 | 125 | -0.528 | 0.625 | 1.414 | -1.915 |
| 66442.0 | 512.0 | 4 | 95 | -0.682 | 1.072 | 1.846 | -2.828 |
| 66601.0 | 671.0 | 5 | 77 | -1.089 | 0.607 | 0.087 | -2.763 |
| 66740.5 | 810.5 | 6 | 64 | -1.157 | 1.136 | 1.586 | -3.288 |
| 66906.0 | 976.0 | 7 | 107 | -0.397 | 1.012 | 4.515 | -2.372 |
| 67052.0 | 1122.0 | 8 | 31 | 0.800 | 0.684 | 2.452 | -0.660 |
| 67172.0 | 1242.0 | 9 | 37 | -0.267 | 0.518 | 0.699 | -1.255 |
| 67289.5 | 1359.5 | 10 | 26 | 0.280 | 0.505 | 1.775 | -0.456 |
| 67443.5 | 1513.5 | 11 | 102 | 1.418 | 0.623 | 2.409 | -0.521 |
| 67646.5 | 1716.5 | 12 | 76 | -1.272 | 0.988 | 1.062 | -3.187 |
| 67817.0 | 1887.0 | 13 | 59 | 1.362 | 0.814 | 3.479 | -0.291 |
| 67951.0 | 2021.0 | 14 | 57 | -0.733 | 1.119 | 1.874 | -2.549 |
| 68080.0 | 2150.0 | 15 | 57 | 0.653 | 1.209 | 2.849 | -1.779 |
| 68235.5 | 2305.5 | 16 | 26 | -0.626 | 0.645 | 0.825 | -1.950 |
| 68376.5 | 2446.5 | 17 | 42 | 1.983 | 0.479 | 2.841 | 0.896 |
| 68508.5 | 2578.5 | 18 | 28 | -0.447 | 0.596 | 0.568 | -1.518 |
| 68725.0 | 2795.0 | 19 | 107 | 0.319 | 0.523 | 1.188 | -1.128 |
| 68940.5 | 3010.5 | 20 | 80 | 0.702 | 0.557 | 1.590 | -0.555 |

## REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | AVERAGE LONGITUDE DIFFERENCE (FEET) LONG | STD DEV LONGITUDE DIFFERENCE (FEET) | MAXIMUM LONGITUDE DIFFERENCE (FEET) | MINIMUM LONGITUDE DIFFERENCE (FEET) |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | -2.943 | 0.950 | -0.542 | -4.713 |
| 66046.5 | 116.5 | 2 | 50 | -2.352 | 1.060 | -0.080 | -4.252 |
| 66257.4 | 327.4 | 3 | 125 | -1.935 | 0.990 | 0.773 | -3.541 |
| 66442.0 | 512.0 | 4 | 95 | -0.871 | 0.790 | 0.853 | -2.460 |
| 66601.0 | 671.0 | 5 | 77 | -0.721 | 0.958 | 1.825 | -2.398 |
| 66740.5 | 810.5 | 6 | 64 | 1.125 | 0.988 | 2.946 | -0.536 |
| 66906.0 | 976.0 | 7 | 107 | -1.603 | 0.724 | 0.248 | -2.981 |
| 67052.0 | 1122.0 | 8 | 31 | 0.168 | 0.535 | 1.267 | -0.752 |
| 67172.0 | 1242.0 | 9 | 37 | -0.652 | 0.822 | 0.851 | -2.050 |
| 67289.5 | 1359.5 | 10 | 26 | -0.876 | 0.588 | 0.142 | -1.982 |
| 67443.5 | 1513.5 | 11 | 102 | 0.494 | 0.908 | 2.500 | -1.818 |
| 67646.5 | 1716.5 | 12 | 76 | -0.264 | 0.868 | 1.428 | -2.240 |
| 67817.0 | 1887.0 | 13 | 59 | 0.068 | 0.937 | 2.578 | -1.582 |
| 67951.0 | 2021.0 | 14 | 57 | -0.966 | 0.942 | 0.745 | -2.932 |
| 68080.0 | 2150.0 | 15 | 57 | 0.804 | 0.681 | 2.723 | -0.698 |
| 68235.5 | 2305.5 | 16 | 26 | 0.132 | 0.637 | 1.204 | -1.247 |
| 68376.5 | 2446.5 | 17 | 42 | -1.459 | 0.783 | -0.085 | -2.756 |
| 68508.5 | 2578.5 | 18 | 28 | -0.456 | 0.751 | 1.039 | -1.778 |
| 68725.0 | 2795.0 | 19 | 107 | 0.237 | 0.849 | 2.066 | -1.455 |
| 68940.5 | 3010.5 | 20 | 80 | 0.460 | 0.961 | 2.491 | -1.659 |
| | | | | | | | |
| | | | | | | | |

REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | AVERAGE ALTITUDE DIFFERENCE (FEET) ALT | STD DEV ALTITUDE DIFFERENCE (FEET) | MAXIMUM ALTITUDE DIFFERENCE (FEET) | MINIMUM ALTITUDE DIFFERENCE (FEET) |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | 2.678 | 1.003 | 4.413 | 0.858 |
| 66046.5 | 116.5 | 2 | 50 | 8.525 | 0.941 | 9.533 | 6.396 |
| 66257.4 | 327.4 | 3 | 125 | 4.738 | 2.311 | 7.392 | -1.105 |
| 66442.0 | 512.0 | 4 | 95 | 0.025 | 1.043 | 2.348 | -1.472 |
| 66601.0 | 671.0 | 5 | 77 | 4.252 | 1.747 | 8.257 | 1.588 |
| 66740.5 | 810.5 | 6 | 64 | 1.602 | 1.348 | 3.777 | -0.910 |
| 66906.0 | 976.0 | 7 | 107 | 2.264 | 1.215 | 4.194 | -0.497 |
| 67052.0 | 1122.0 | 8 | 31 | 3.192 | 0.208 | 3.630 | 2.718 |
| 67172.0 | 1242.0 | 9 | 37 | 4.585 | 0.371 | 5.332 | 3.716 |
| 67289.5 | 1359.5 | 10 | 26 | 0.600 | 0.170 | 0.965 | 0.307 |
| 67443.5 | 1513.5 | 11 | 102 | 2.852 | 0.737 | 4.172 | 0.318 |
| 67646.5 | 1716.5 | 12 | 76 | -0.945 | 0.605 | 0.301 | -2.206 |
| 67817.0 | 1887.0 | 13 | 59 | 2.485 | 0.973 | 3.752 | 0.643 |
| 67951.0 | 2021.0 | 14 | 57 | 1.967 | 0.351 | 2.978 | 1.382 |
| 68080.0 | 2150.0 | 15 | 57 | -2.800 | 1.419 | -0.006 | -4.548 |
| 68235.5 | 2305.5 | 16 | 26 | 0.031 | 1.067 | 2.067 | -1.619 |
| 68376.5 | 2446.5 | 17 | 42 | 7.835 | 0.861 | 9.568 | 6.450 |
| 68508.5 | 2578.5 | 18 | 28 | 2.618 | 0.208 | 3.103 | 2.259 |
| 68725.0 | 2795.0 | 19 | 107 | 5.034 | 1.068 | 7.214 | 2.767 |
| 68940.5 | 3010.5 | 20 | 80 | 0.813 | 1.403 | 2.890 | -1.527 |

## REAL-TIME GPS vs OPTICS DIFFERENCE STATISTICS

| AVERAGE TIME | ELAPSED TIME FROM START (SEC) | RUN NO | NUMBER OF POINTS | | LINEAR ERROR PROBABLE REALTIME | CIRCULAR ERROR PROBABLE REALTIME | SPHERICAL ERROR PROBABLE REALTIME |
|---|---|---|---|---|---|---|---|
| 65943.5 | 13.5 | 1 | 26 | | 0.676407751 | 0.872006199 | 1.272715284 |
| 66046.5 | 116.5 | 2 | 50 | | 0.634858911 | 0.936682341 | 1.297406409 |
| 66257.4 | 327.4 | 3 | 125 | | 1.559048257 | 0.950649799 | 2.011942 |
| 66442.0 | 512.0 | 4 | 95 | | 0.703671286 | 1.096481857 | 1.488729393 |
| 66601.0 | 671.0 | 5 | 77 | | 1.17805855 | 0.921671376 | 1.697178595 |
| 66740.5 | 810.5 | 6 | 64 | | 0.909120351 | 1.250180721 | 1.778588694 |
| 66906.0 | 976.0 | 7 | 107 | | 0.819521977 | 1.022315884 | 1.512251522 |
| 67052.0 | 1122.0 | 8 | 31 | | 0.140545361 | 0.717429092 | 0.730977784 |
| 67172.0 | 1242.0 | 9 | 37 | | 0.249903405 | 0.789018198 | 0.876372421 |
| 67289.5 | 1359.5 | 10 | 26 | | 0.114619303 | 0.643296269 | 0.646778424 |
| 67443.5 | 1513.5 | 11 | 102 | | 0.497197323 | 0.901096564 | 1.161823976 |
| 67646.5 | 1716.5 | 12 | 76 | | 0.407782068 | 1.092630086 | 1.260502546 |
| 67817.0 | 1887.0 | 13 | 59 | | 0.656600321 | 1.031035737 | 1.396017335 |
| 67951.0 | 2021.0 | 14 | 57 | | 0.23668427 | 1.213276251 | 1.235430384 |
| 68080.0 | 2150.0 | 15 | 57 | | 0.957151737 | 1.112757584 | 1.695534418 |
| 68235.5 | 2305.5 | 16 | 26 | | 0.719701123 | 0.755180363 | 1.20397977 |
| 68376.5 | 2446.5 | 17 | 42 | | 0.581033548 | 0.742684439 | 1.087720959 |
| 68508.5 | 2578.5 | 18 | 28 | | 0.140504123 | 0.792844588 | 0.796557926 |
| 68725.0 | 2795.0 | 19 | 107 | | 0.720590173 | 0.808096909 | 1.250692842 |
| 68940.5 | 3010.5 | 20 | 80 | | 0.946389172 | 0.893481899 | 1.496585023 |
| | | | | MEANS: | 0.64246945 | 0.927140808 | 1.294889285 |

## APPENDIX F. ABBREVIATIONS

| | |
|---|---|
| app | - appendix |
| ATTC | - U.S. Army Aviation Technical Test Center |
| fig. | - figure |
| GPS | - global positioning system |
| GMT | - Greenwich mean time |
| IAW | - in accordance with |
| No. | - number |
| RMS | - root mean square |
| SEP | - spherical error probable |
| TDARDS | - Truth Data Acquisition Recording And Display System |
| TSPI | - time-space positioning information |
| TECOM | - U.S. Army Test and Evaluation Command |
| WSMR | - White Sands Missile Range |

APPENDIX G. DISTRIBUTION LIST

| ADDRESSEES | REPORT |
| --- | --- |
| Commander<br>U.S. Army Test and Evaluation Command<br>ATTN: AMSTE-CT-T<br>AMSTE-TA-L<br>Aberdeen Proving Ground, MD 21005-5055 | <br><br>3<br>1 |
| Commander<br>White Sands Missile Range<br>ATTN: STEWS-TD-P<br>NRO-DR-S (Mr. Tony Palomino)<br>White Sands Missile Range, NM 88002 | <br><br>1<br>1 |
| Defense Technical Information Center<br>8725 John J. Kingman Road, Suite 0944<br>Fort Belvoir, VA 22060-6218 | 1 |